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THE SALT REQUIREMENTS OF LUPINUS ALBUS

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Received for publication August 15, 1925

The seedlings of *Lupinus albus* have been found to be so well adapted to certain kinds of physiological work that it became desirable to determine the composition of a solution which would perform the same function in the study of its physiology that Shive's (2) optimum solution has for wheat.

Solution and sand cultures were used and manipulated in general as recommended by the Committee on the Salt Requirements of Plants (1), except for certain details here noted. The solution cultures were renewed every four days. The plants were grown in 500-cc. beakers (tall form) containing 400 cc. of the solution. For the sand cultures 1250 gm. of thoroughly washed "Juniata" sand was placed in liter pyrex beakers (tall form). The water content was held at 62.5 per cent of the water-holding capacity. The salt combinations used were: Series I—K_2SO_4, $CaH_4(PO_4)_2$, $Mg(NO_3)_2$; Series II —KNO_3, $CaSO_4$, $MgH_4(PO_4)_2$; Series III—KH_2PO_4, $Ca(NO_3)_2$; $MgSO_4$. In each series three total salt concentrations in respect to the cation were used: X, 0.0021 N; 4X, 0.0084 N; 16X, 0.0336 N. The concentration of the anions was the same except as modified by the nature of the phosphate salt which gave the PO_4 ion a normality three times that of the other anions. This particular method of making up the solutions was chosen to facilitate the comparison of chemical equivalents when represented diagrammatically by the triangle system. (For the salt ratios see table 1.) Iron was supplied as ferric citrate in amounts proportional to the total salt concentration of the solutions. All seeds were carefully selected by weight, germinated in moist sand, and the most vigorous 25 per cent of the seedlings was selected for the cultures.

Series 1 was grown in a greenhouse for 25 days during March. The average daily loss from a white spherical atmometer was 15.8 cc. The average daily range in temperature was 24.4° to 18.3°C., with a daily mean of 21°C., and maximum and minimum temperatures of 30°C. and 10°C. Series II was grown in the same greenhouse for 25 days in May. The average daily loss from a white spherical atmometer was 18.1 cc. The average daily range in temperature was from 28° to 14°C. The maximum temperature was 32°C. which was approximated on several days. The latter temperature is probably too high for the best growth of *Lupinus albus*. Series III was grown for 32 days during July and August on an outside lattice work bench which could be covered during rains. The plants were shaded with a translucent white

oilcloth, from 11 a.m. to 3 p.m., on clear days when the temperature exceeded 20°C. The average daily loss from a black spherical atmometer was 24.7 cc. The average daily range in temperature was between 31.5° and 18°C. A maximum of 38°C. was approximated on 3 days. Regardless of the high temperatures prevailing during this experiment, the plants were superior to those grown in the previous series. The condition of the plants in the best cultures indicated that they might have been kept growing indefinitely.

EXPERIMENTAL RESULTS

In table 1 are shown the salt ratios as well as the relative growth in the various solutions. The results are shown graphically in figure 1. The highest yielding cultures as well as the highest average yield for all cultures of a series tend strongly to occur in the 4X concentration. There is an ap-

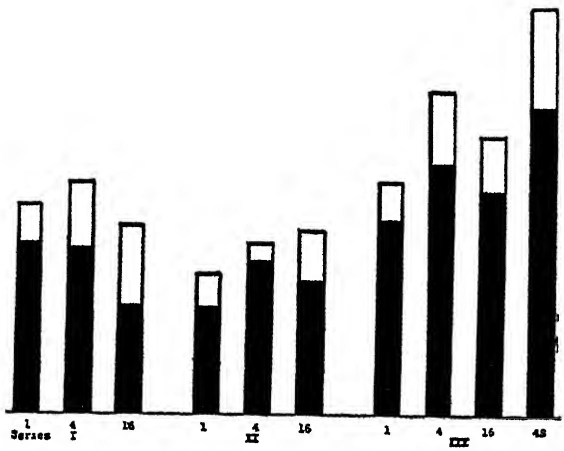

FIG. 1. RELATIVE GROWTH OF TOPS

All weights are calculated on the basis of the green weight of culture 9, 4X concentration of series III, as 100 per cent. Solid portion indicates the average yield of all cultures of a concentration; open portion, the relative yield of the best culture; "1," "4," and "16" indicate the total salt concentrations; "S" indicates sand culture.

parent exception to this in series II, 16X. The difference, however, is slight and the high yielding cultures in the high concentration are all relatively low in phosphate.

The roots were generally best developed and of the best color, in the 4' solutions. In the lower concentration they tended to become brownish a' soft. The tap roots were short and thick and developed few secondary roc The secondary roots were best developed in the 16X concentration, exc when their development was retarded by the acidity of the solution. relative average yields of all cultures of the same concentration of a s as well as the relative weights of the roots in the culture producing the ' est yield, are shown in figure 2.

The effect of the various salt concentrations on the water requirement per gram of green weight of tops produced is shown in figure 3. The concentration of the solution had relatively little effect on the transpiration per unit w' ght produced, although there is an indication of a slightly higher

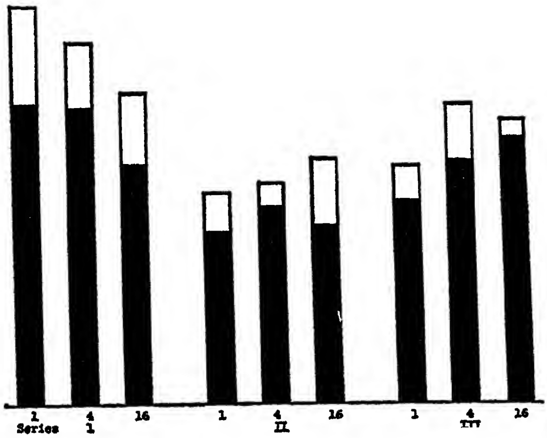

FIG. 2. RELATIVE GROWTH OF ROOTS, BASED ON THE DRY W IGHT OF CULTURE 9. 4X CONCENTRATION SERIES III

Labels as in figure 1

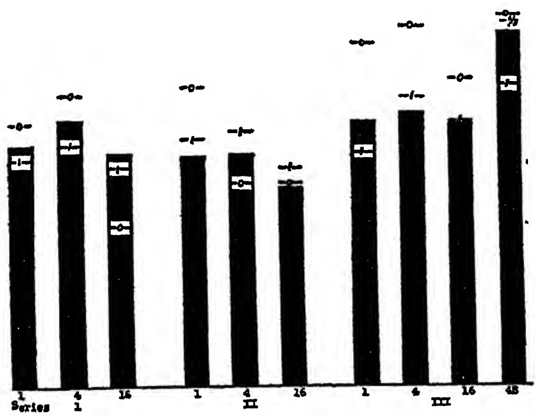

FIG. 3. RELATIVE TRANSPIRATION PER GRAM OF GREEN WEIGHT PRODUCED

Height of the solid portion indicates the average for all cultures; -1- indicates the transpiration for the best culture, -0-, for the poorest; -0- for the sand culture is only ⅗ of its relative height. Labels as in figure 1.

requirement in the 4X co ses, the low yielding cultures show a high water r on can be drawn concerning the effect of the vari transpiration because of

the different environmental conditions prevailing during the growth of each series.

A careful record was kept of the H-ion concentration of the original solutions and of the effect of the growth of the plant on its reaction. The H-ion concentrations of the original solutions ranged in series I, from pH 3.2 to 4.2; in Series II, from pH 3.4 to 4.4; in series III, from pH 3.8 to 4.8. All solutions with an original acidity greater than pH 3.6 gave low yields, even when the reaction of the original solution was quickly changed by the plants. The strong buffer action of the 16X solutions in series I and II probably accounts

TABLE 1

Relative yield of cultures based on the green weight

NUMBER	CONCENTRATION SALT RATIOS			SERIES I			SERIES II			SERIES III			SAND* CULTURES
	K.	Ca.	Mg.	X	4X	16X	X	4X	16X	X	4X	16X	
1	1	1	4	123	133	88	72	73	39	59	88	89	74
2	1	2	3	112	122	55	86	90	64	70	108	98	73
3	1	3	2	110	56	35	78	107	77	53	87	94	82
4	1	4	1	107	50	22	43	105	116	71	99	83	74
5	1½	1½	3	113	100	98	70	87	77	54	71	99	
6	1½	2¼	2¼	100	118	54	68	91	62	79	101	90	
7	1½	3	1½	112	82	38	92	110	78	75	95	99	
8	2	1	3	104	135	84	59	96	37	86	86	79	72
9	2	2	2	108	100	60	81	100	80	79	100	98	100
					14.8†			12†			21.9†		27.4†
10	2	3	1	93	58	40	71	110	114	76	103	72	75
11	2¼	1½	2¼	119	134	74	68	106	93	74	63	109	
12	2¼	2¼	1½	104	88	58	88	110	96	70	114	69	
13	3	1	2	98	95	112	61	104	73	65	94	85	57
14	3	1½	1½	88	98	94	61	84	95	79	82	79	
15	3	2	1	107	80	53	63	112	96	91	108	98	67
16	4	1	1	97	109	45	46	111	100	59	107	88	40
Average.......				99.7	96.2	63.1	69.6	99.7	88.1	70.6	97.7	86.5	75.9
Variation....				+23	+39	+49	+23	+12	+28	+21	+11	+23	+24
				±12	−46	−41	−26	−27	−41	−17	−34	−17	−35

* Same salt combination as series III, 4X concentration. The relative weights of 9 in the X and 16X concentrations were 63 and 82 per cent respectively. The plants in the latter culture were stongly chlorotic.

† Weight of no. 9, 4X, in grams.

for the extremely poor yields of the cultures high in phosphate. This was plainly evident when the acidity was associated with a high calcium concentration. The roots were unable to penetrate the solution in cultures 3, 4, 7, and 10 of series I and 16X concentration. The growth of the plants in series II changed the reaction of the solutions only slightly. Certain cultures, peculiarly, tended to become more acid with the limit at pH 3.7. This was the reaction after 4 days in several of the highest yielding cultures. The critical H-ion concentration for *Lupinus albus* is somewhere between pH 3.4

and 3.6 when the acidity is due to phosphoric acid formed by the dissociation of a monobasic phosphate.

DISCUSSION

A study of the results does not indicate that a certain specific ratio of the cations is required. There is no evidence to justify the term "calciphobe" as formerly applied by ecologists to *Lupinus albus*. When the results are plotted graphically by means of the triangle system, and the anions rather than the cations are placed at the apices, specific effects are shown for certain concentrations of the anions. In the X and 4X concentrations, the concentration of the nitrate ion seems to be a limiting factor. At least, there is a strong tendency for the low yields to be associated with a low nitrate concentration (fig. 4 and 5). As the total concentration of the solution is increased,

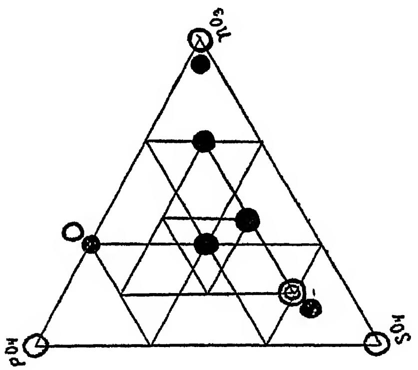

FIG. 4

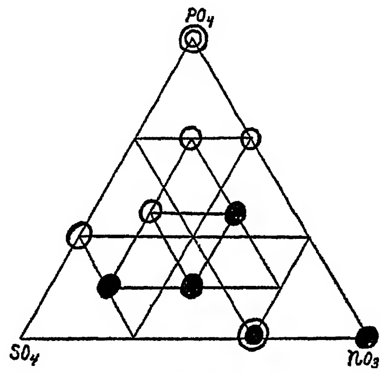

FIG. 5

FIG. 4. GRAPH TO SHOW DISTRIBUTION OF HIGHS AND LOWS IN RELATION TO THE ANIONS IN THE 0.0021 *N* SALT CONCENTRATION

Two highs and lows are taken from each series. The solid circles indicate highs, the open circles lows. Two concentric circles indicate two lows at that point, a solid center indicates two highs.

FIG. 5. AS IN FIGURE 4, EXCEPT FOR A TOTAL SALT CONCENTRATION OF 0.0084 *N*

the high yielding cultures tend to shift from the nitrate to the sulfate apex, with strong tendencies away from the phosphate apex. This also applies to series III in which acidity was not a limiting factor (fig. 4, 5 and 6). This tendency was particularly well shown in the sand cultures (fig. 7) in which after the beginning of the growth of the plants, a H-ion concentration of pH 5 to 5.6 was maintained. All cultures at the phosphate apex were strongly chlorotic and did not develop normal coloration upon the addition of increased amounts of iron. This was also true of sand culture 9, 16X concentration. The effect of the anions on the yield is clearly shown by a comparison of the average yield of the three cultures at each apex. When the central culture is given as 100 per cent, the yields were: PO_4 apex, 54 per cent;

SO_4 apex, 78 per cent; NO_3 apex, 82 per cent. It must not be forgotten in considering these results that the *normal* concentration of the phosphate ion is three times that of the sulfate and nitrate ions.

The investigations here reported (because of the inherent difficulties encountered in work of this nature) are necessarily only preliminary and any future researches will surely modify the results. The author does feel, however, that he has obtained sufficient information to justify the original object of the investigation. The use of *Lupinus albus* in salt balance work will probably not be continued here because climatic conditions in eastern Pennsylvania are unfavorable for growing it to maturity.

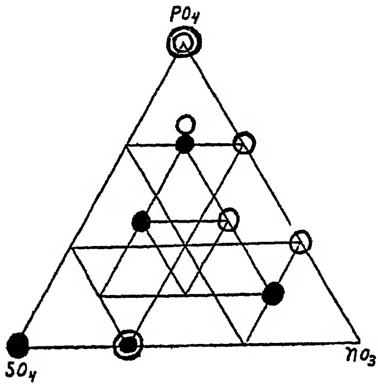

FIG. 6

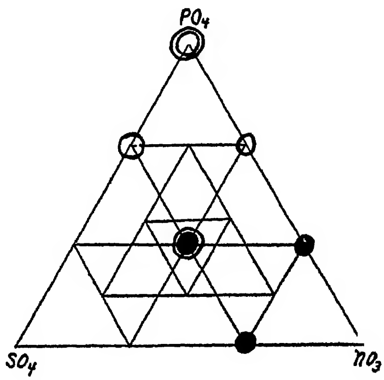

FIG. 7

FIG. 6. AS IN FIGURE 4, EXCEPT FOR A TOTAL SALT CONCENTRATION OF 0.0336 *N*

FIG. 7. HIGHS AND LOWS IN THE SAND CULTURES

Open circles indicate lows; open concentric circles, the poorest culture; solid circles, highs; solid center with a concentric circle, the best culture. Total salt concentration, 0.0084 *N*.

SUMMARY

A very favorable total salt concentration for the growth of *Lupinus albus* is 0.0084 *N* when calculated in respect to the cations.

The salt ratios should be 5:3:4 for potassium, calcium, and magnesium; or 5:9:4 for the nitrate, phosphate, and sulfate ions, respectively. A solution composed of 0.0035 *N* KNO_3, 0.0021 *N* $CaH_4(PO_4)_2$, and 0.0028 *N* $MgSO_4$, will produce a favorable growth when the H-ion concentration is less than pH 3.6.

High concentrations of phosphate tend to produce chlorosis.

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(1) LIVINGSTON, B. E., (Editor) 1919 A Plan for Coöperative Research on the Salt Requirements of Representative Agricultural Plants. Div. Biol. and Agr. of Natl. Res. Council, Baltimore.

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EFFECTS OF VARIOUS METHODS OF APPLYING FERTILIZERS ON CROPS AND ON CERTAIN SOIL CONDITIONS[1]

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One of the most important problems in American agriculture today is the correct usage of commercial fertilizers. The increased tonnage of fertilizers sold in the eastern and southern states and the marked benefits from various materials on western soils, indicate definitely that the use of commercial fertilizers in the United States is destined to grow rapidly. With their use, however, comes the question of the proper method of application.

The two common methods employed in the distribution of fertilizers are by broadcasting and by applications at the hill or along the drill-row. Most farmers prefer the latter localized method as it avoids a separate operation and often gives more profitable increases in crop yields. But it may frequently result in injury to seed germination and to plant growth, as is apparent from many studies. Some of the potato and cotton planter manufacturers are attempting to eliminate the danger of this *burning* effect of fertilizers by locating them *above* the seed with soil interposed, *below* the seed, at the *sides*, or rather thoroughly *mixed with the soil in the seed row*. It has been noted that plants vary among themselves as to this injury too, the legumes and cotton being much more sensitive to fertilizer burning than the cereals.

Although there is some diversity of opinion as to the nature of the injury, several investigators have concluded that it is due to the increased osmotic pressure of the soil solution and to the consequent retardation in absorption of water by the seed. Some have found a relationship between the inhibited germination or retarded plant growth and a stimulation in the growth of fungi brought about by the fertilizer. A caustic or *burning* effect of certain fertilizers on the seed or plant roots has been noted in many tests. The injury to plant growth from *hill* fertilization has also been attributed to drought brought about by an over-luxuriant vegetative growth, which in-

[1] Part I of a thesis (without historical section, bibliography and photographs) presented to the faculty of the Iowa State College in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

[2] The writer wishes to thank Dr. P. E. Brown for his kindly interest and helpful advice during the progress of this work. Indebtedness to Dr. Paul Emerson, Prof. L. W. Forman, and Prof. L. C. Burnett, for their assistance and timely suggestions, is also gratefully acknowledged. The establishment, by the National Fertilizer Association, of the fellowship which made possible this research has likewise been deeply appreciated.

creases the water requirements of the plants. Restricted root development may in part be the cause of growth injury.

It has been shown that the climatic or seasonal condition, especially the rainfall, is one of the most important factors influencing the occurrence of injurious effects from fertilizers. The concentration or size of application is always of large significance as is also the composition of the fertilizer, the greatest injury occurring when the more soluble chemical fertilizers are used. This fact becomes all the more important when it is noted that the trend of the fertilizer industry is toward chemical mixtures, as for example. the nitrate plants built to make air-nitrates.

The effect of soil type and the movement of salts in soils have been studied by several investigators, and varying results have been secured. The rate of diffusion certainly plays a large part in determining the effects of fertilizers.

EXPERIMENTAL

The experimental work reported in the following pages involved studies of the effects of numerous fertilizers upon seed germination, upon plant growth, and upon certain soil conditions, with various methods of applying the fertilizer relative to the drill-row and hill. Studies of root spread and fertilizer movement through soils watered in several ways were also conducted. The tests were all hand planted both in the field and in the greenhouse.

Field germination tests

These tests were conducted on the Agronomy Farm and various fertilizers were compared as to their toxicity upon corn germination, when applied in *direct contact in the drill-row* at planting, *direct contact in the hill*, *below the row*, *below the hill*, *above the row*, and *at the side of the row*. Tables 1, 2, 3, 4 and 5 give the outlines of the respective tests and the data secured. Germination counts were made at intervals of several days but only the first and last counts are given.

In all of the *row* studies, the fertilizer application was tested in a row 3½ feet long with 1-foot intervals between and 20 kernels planted for each treatment. The *hill* treatments comprised 5 hills of 10 kernels each, except in the *below the hill* studies where 25 kernels represented a perfect stand.

The fertilizer applications were based upon hills 42 inches square and required 12.757 gm. per hill, *equivalent to 100 pounds per acre*. A tin box 2 inches wide by 3 inches long with the bottom removed, served to make the applications uniform in surface spread and depth of planting in all of the *hill* studies. The *row* tests received each fertilizer as a strip 1-inch wide. The commercial 2–12–2 used in all of these tests was Armour's Big Crop brand. The chemical 2–12–2 was home-mixed, using nitrate of soda, acid phosphate, and muriate of potash. The soil type was Carrington loam, a dark brown upland soil of rather high productivity and extensively found in the Wisconsin drift area of Iowa.

The rainfall interfered very markedly with the germination results and undoubtedly there was less injury than would have been found under conditions of continuous dry weather. Nevertheless, 16 per cent acid phosphate retarded germination for all of the rates used in the *direct contact in the row*

TABLE 1

*Germination counts of corn hand drilled and fertilized direct contact in the row**

FERTILIZER APPLICATIONS RATE PER ACRE	ACID PHOSPHATE (16 PER CENT)		COMMERCIAL 2-12-2		CHEMICAL 2-12-2		MIXED 0-12-2	
	Days after planting on which the counts were made							
	8	15	8	15	8	15	8	15
pounds								
Check	17	20	17	20	17	19	16	19
100	8	20	10	17	1	19	2	20
150	4	20	1	14	1	20	2	19
200	7	19	0	5	0	20	0	19
250	2	18	0	8	0	15	0	15
300	1	14	0	4	0	15	0	13
350	0	12	0	3	0	13	0	11
400	0	13	0	1	0	7	0	12
450	0	8	0	2	0	9	0	6
Check	16	20	18	19	14	19	16	20

RATE PER ACRE	ROCK PHOSPHATE		RATE PER ACRE	NITRATE OF SODA		MURIATE OF POTASH (AMERICAN TRONA CORP.)	
	Days after planting on which counts were made			Days after planting on which the counts were made			
	8	15		8	15	8	15
pounds			*pounds*				
Check	19	19	Check	20	20	18	20
100	19	19	25	14	20	2	20
150	20	20	50	5	19	1	19
200	19	20	75	0	17	0	14
250	18	20	100	0	14	0	4
300	19	19	125	0	6	0	1
400	20	20	150	0	5	0	1
500	20	20	175	0	1	0	2
600	19	20	200	0	0	0	0
Check	17	19	Check	19	20	19	20

* Twenty plants per 3½ feet of row represent a perfect germination.

studies shown in table 1. It failed to show prevention of germination, however, until 300 pounds per acre was applied, when a 70 per cent stand was secured. Of all of the fertilizers tested, it was the least toxic in its effect upon corn germination, except of course raw rock phosphate. The other fertilizers all injured germination, varying considerably as to the limits of

their toxicity. The commercial 2–12–2 gave pronounced injury at about 200 pounds per acre. In fact, this rate reduced the germination to 25 per cent of a perfect stand.

The applications of nitrate of soda alone and of muriate of potash alone produced the greatest injury. All rates tested, even 25 pounds per acre, gave a retarded germination. The respective breaking points, or rates at

TABLE 2

The effect of various fertilizer locations relative to the seed in the row upon corn germination

FERTILIZER APPLICATIONS RATE PER ACRE	1 INCH BELOW SEED		1 INCH ABOVE SEED		1 INCH SIDE OF SEED	
	Days after planting on which the counts were made					
	10	20	10	20	10	20
	Nitrate of soda					
pounds						
Check	20	20	20	20	14	20
100	0	1	18	18	12	18
150	0	2	14	18	17	19
200	0	1	15	16	16	18
250	1	1	8	13	18	20
300	0	1	7	12	9	19
350	0	0	9	9	17	19
400	0	0	4	7	19	20
450	0	1	2	2	14	18
Check	19	20	20	20	16	19
	Commercial 2–12–2					
Check	19	19	18	18	20	20
100	15	20	20	20	20	20
200	17	20	19	20	19	19
300	9	17	19	20	19	20
400	12	16	20	20	18	19
500	1	11	20	20	20	20
600	0	6	20	20	17	18
700	0	2	19	19	19	20
800	0	0	18	19	16	19
Check	19	20	19	20	20	20

which actual inhibition of germination occurred, were 125 and 100 pounds per acre. The fact that 0.84 inches of rain fell just 3 days after planting, should be emphasized, for the breaking points were undoubtedly raised by 50 pounds or more. At the 100-pound rate, the muriate permitted only a 20 per cent stand.

Where the fertilizers were applied *1 inch below*, *1 inch above*, and *1 inch to one side* of the seed row (table 2), the upward movement of the soluble

fertilizer salts through the soil and the injury to corn germination are very apparent, especially in the case of nitrate of soda. Even the lowest rate tested—100 pounds per acre—gave complete inhibition. The commercial 2-12-2 showed the same tendency, only to a lesser degree. The *above* treatments permitted good germination with the commercial 2-12-2, but inhibited germination with the high applications of the nitrate of soda. This was very likely due to the downward diffusion of the nitrate, even under the prevailing conditions of dry weather.

TABLE 3

*Germination counts of corn fertilized in the hills**

FERTILIZER APPLICATIONS RATE PER ACRE	ACID PHOSPHATE (16 PER CENT)		COMMERCIAL 2-12-2		CHEMICAL 2-12-2	
	Days after planting on which the counts were made					
	9	15	9	15	9	15
pounds						
Check	27	47	47	49	44	46
20	23	50	17	45	38	47
40	25	46	2	19	23	46
60	24	41	0	6	11	39
80	21	31	0	0	5	31
100	11	18	0	0	0	13
120	9	17	0	0	0	4
140	1	7	0	0	0	0
160	0	1	0	0	0	0
Check	36	43	47	47	46	47

RATE PER ACRE	NITRATE OF SODA		SULFATE OF AMMONIA	
	Days after planting on which the counts were made			
	9	15	9	15
pounds				
Check	47	47	47	48
5	17	48	41	50
10	8	44	24	50
20	0	42	8	46
30	0	22	2	41
40	0	9	2	33
50	0	6	0	17
60	0	0	0	5
75	0	0	0	1
Check	46	48	45	48

* Fifty plants represent a perfect germination.

Absolutely no injury to germination, either retardation or inhibition, was detected from any of the fertilizers applied along the *side* of the seed row with

soil interposed. These results are in agreement with the writer's previous findings in New Jersey for both rainy and dry seasons.

TABLE 4

*Germination counts of corn fertilized 1 inch below seed in the hills**

FERTILIZER APPLICATIONS RATE PER ACRE	ACID PHOSPHATE (16 PER CENT)		COMMERCIAL 2-12-2		NITRATE OF SODA	
	Days after planting on which the counts were made					
	9	15	9	15	9	15
pounds						
Check	24	25	25	25	25	25
100	12	24	15	25	18	24
150	21	25	15	25	2	23
200	24	25	11	24	0	23
250	23	25	13	23	0	11
300	16	24	9	22	0	8
350	21	24	5	17	0	7
400	8	21	0	18	0	0
450	5	18	0	15	0	1
Check	25	25	25	25	23	25

* Twenty-five plants represent perfect germination.

TABLE 5

*Effect on corn germination of varying the width of fertilizer strip, located 1 inch below the seed in the row**

FERTILIZER TREATMENTS		WIDTH OF FERTILIZER STRIP					
Kind	Rate per acre	1-inch		2-inch		4-inch	
		Days after planting on which counts were made					
		9	15	9	15	9	15
	pounds						
Acid phosphate (16 per cent)......	200	17	20	18	20	20	20
	400	18	20	19	19	20	20
Chemical 2-12-2................	200	14	20	17	18	19	20
	400	12	15	14	17	14	20
Nitrate of soda..................	200	1	3	0	7	2	12
	400	0	0	0	2	0	4

* Twenty plants represent a perfect germination.

In table 3, the effects of *direct contact in the hill* applications of fertilizers are shown. The results of an additional test with acid phosphate and commercial 2-12-2 are not given, as they were quite similar to those presented.

Again acid phosphate proved the least injurious of the various fertilizers tested. However, its breaking point was around 100 pounds per acre, or much lower than when applied in *direct contact in the row.*

The commercial 2–12–2 gave a pronounced injury and its breaking point was between 20 and 40 pounds per acre. Applications of 80 pounds and more completely prevented germination. This occurred under conditions of high moisture content in the soil too, for it rained 0.76 inch just two days prior to the planting. The nitrate of soda and the sulfate of ammonia also gave badly injured corn germination. The breaking point of the former was between 30 and 40 pounds per acre, whereas for the latter it was about 60 pounds.

From these results it appears that all fertilizer attachments permitting the *direct contact in the hill* location of fertilizers are very undesirable for use.

The effects upon corn germination of three fertilizers when located *1 inch below the hill* are given in table 4. Rainfall on the day following the planting and three days later certainly affected the results; nevertheless, the injury from the nitrate of soda was marked. It showed a breaking point of 250 pounds per acre, at which application there was a 40 per cent germination. The acid phosphate and the commercial 2–12–2 gave no positive inhibition of germination, but retarded the germination for all of the rates tested. The *below* location of fertilizers evidently will not eliminate the dangers to seed germination.

Table 5 shows the results of a study of the effects upon germination of varying the width of the fertilizer strip located *1 inch below the seed row.* In general it was found that the wider the strip for a given fertilizer at a given depth below the seed in this soil, the less was the injury to germination. This fact was again shown best by the nitrate, but the chemical 2–12–2 also indicated it. The acid phosphate failed to give any noticeable retardation of germination for the various rates of application tested.

If *below* methods of fertilizer distribution are used, provision should certainly be made for adjusting the area of spreading the fertilizer or the width of its strip and the depth below the seed-row or hill. But it has not been shown conclusively that there is no danger to root development and seedling growth from large applications of concentrated soluble chemical fertilizers located *below the hill or the drill-row* and hence the method is not recommended. The results do seem to indicate, however, that *side* locations of the fertilizer are safe to germination and effective in benefits.

Greenhouse studies

Some row and hill fertilization studies were made under control conditions in the greenhouse. Wheat and oats were grown in benches with row applications of the commercial 2–12–2 fertilizer, applied in treatment-lengths of 1 and 5 feet respectively. On the basis of these treatment-lengths and with a 7-inch interval, the wheat received 2.43 grams whereas the oats

received 12.15 grams per 400 pounds per acre application. The Ammo-Phos plus KCl treatment used on the oats was applied at ¼ the rate of the 2-12-2. Tables 6 and 7 give the respective outlines of the tests and the dry harvest weights after 10 weeks' growth.

TABLE 6

Greenhouse study of methods of fertilizing wheat

TREATMENT NUMBER	METHODS OF APPLYING THE FERTILIZER RELATIVE TO THE SEED ROW (COMMERCIAL 2-12-2)	DRY HARVEST WEIGHTS PER TREATMENT FOR THE FOLLOWING RATES OF FERTILIZER APPLICATION IN POUNDS PER ACRE				
		Check (none)	200 pounds	400 pounds	600 pounds	800 pounds
		gm.	*gm.*	*gm.*	*gm.*	*gm.*
1	One side of row, 1 inch away, same plane	18.0	21.0	20.5	23.0	25.5
2	Both sides of row, split, 1 inch away, same plane	15.0	19.5	21.0	21.5	23.0
3	Both sides of row, split, ½ inch away, same plane	16.0	19.0	22.0	23.0	26.0
4	Both sides of row, split, 1 inch away, 1 inch lower plane	20.0	22.5	26.0	26.0	29.0
5	1 inch below seed row	17.5	25.0	23.5	27.0	28.0
6	½ inch below seed row	22.0	27.0	29.5	33.0	32.0
7	½ inch above seed row	21.0	20.0	24.0	27.0	25.0
8	Direct contact in seed row	24.0	33.0	42.0	46.0	37.5

TABLE 7

Greenhouse study of methods of fertilizing oats

TREATMENT NUMBER	METHOD OF APPLYING THE FERTILIZER RELATIVE TO THE SEED ROW	DRY HARVEST WEIGHTS (10 WEEKS' GROWTH)	
		Commercial 2-12-2 (400 pounds per acre)	Ammo-Phos + KCl (100 pounds per acre)
		gm.	*gm.*
1	Check—unfertilized	176	164
2	Direct contact in seed row	195	182
3	One side of row, 1 inch away, same plane	200	191
4	1 inch below seed row	205	197
5	1 inch above seed row	190	169
6	Check—unfertilized	180	158

The *direct contact* fertilization with rates of application tested, allowed a very satisfactory growth of the wheat. The high rates, however, proved somewhat depressing to growth. Undoubtedly, the frequent waterings decreased the injury so that under normal field conditions a safe germination and good growth could be expected only at much lower rates. The *above* fertilization

gave small benefits, but they were probably larger than would have been realized in the field in a dry season. The *below* and *sides* locations of the fertilizer gave fair responses, but were not so effective as the *direct contact*.

With the oats the *direct contact* fertilization brought about increases in growth, but the *below* and the *side* applications gave the largest beneficial effects. Again the *above* location of the fertilizer led to small yields. The results were similar for both fertilizers tested. It appears from these results that moderate applications of fertilizers distributed *direct contact* in the seed rows will give very satisfactory results for cereals like wheat and oats, which are very resistant to fertilizer burning.

TABLE 8

Greenhouse study of hill locations of fertilizer on corn

TREATMENT NUMBER	FERTILIZER LOCATION RELATIVE TO HILL*	AVERAGE PLANT HEIGHTS	DRY HARVEST WEIGHTS
		inches	*gm.*
1	1 inch above hill, strip 1 inch by 4 inches	40	43
2	1 inch below hill, strip 1 inch by 4 inches	50	52
3	Check—unfertilized	45	40
4	One side of hill, 1 inch away, same plane, strip 1 inch by 4 inches	65	67
5	Rear of hill, 1 inch away, same plane, strip 1 inch by 4 inches	60	43
6	Both sides of hill, split, 1 inch away, same plane, strip 1 inch by 4 inches	70	57
7	Check—unfertilized	50	42
8	Both sides of hill, split, 1 inch away, 1 inch lower plane, strip 1 inch by 4 inches	70	56
9	Band around hill, 1 inch away, same plane, 1 inch width	60	48

* Two hills per treatment, each receiving 12.75 grams of Commercial 2–12–2, which is equivalent to 100 pounds per acre.

In the greenhouse study of corn fertilization reported in table 8, Reid's Yellow Dent seed was planted with 4 kernels per hill. The crop was harvested at two different periods of growth, but only the final harvest yields are given with the average plant heights, as the results were very similar at the two harvests.

The results indicate that the *sides of hill* location for the fertilizer is beneficial and certainly equal to any of the other methods tested. Both the *sides* and the *below* locations gave results superior to the *rear of hill* and the *above the hill* positions.

Field fertilizer studies—hill methods

Table 9 outlines a test of hill methods of applying the fertilizer, which was planted in duplicate on the Agronomy Farm. Ammo-Phos plus muriate of potash was used. Two days after planting, 2.10 inches of rain

fell, which aided the *above the hill* fertilization and reduced the injury from the *below* locations. Nevertheless, the high applications *below* gave considerable injury and the *above* applications failed to equal the small *below* or *both sides* applications.

A study of the effects of area of spread of the fertilizer *below* the seed in the hill was also made. The results show that increased area of spread and increased depth of locating the fertilizer serve to safe-guard the seed germination and the seedling growth.

TABLE 9

Field study of hill methods of applying the fertilizer

TREATMENT NUMBER	FERTILIZER APPLICATIONS		DRY HARVEST WEIGHTS
	Per hill	Location relative to hill	
	gm.		*pounds*
1	9.18	1 inch below, 2 inches by 5 inches spread	7.5
2	18.36	1 inch below, 2 inches by 5 inches spread	4.0
3	18.36	1 inch below, 4 inches by 5 inches spread	7.1
4	18.36	1 inch above, 4 inches by 5 inches spread	6.5
5	None	Check	1.5
6	18.36	1 side, 1 inch away, 2 inches by 5 inches spread, same plane	6.0
7	18.36	Both sides, split, 1 inch away, 2 inches by 5 inches spread, same plane	7.0
8	18.36	Band around hill, 1 inch away, same plane	6.7
9	18.36	Both sides, split, 2 inches by 5 inches spread, 1 inch lower plane	7.4
10	36.72	1 inch below, 2 inches by 4 inches spread	1.1
11	36.72	1 inch below, 4 inches by 4 inches spread	4.5
12	36.72	1 inch below, 6 inches by 6 inches spread	6.3
13	36.72	2 inches below, 4 inches by 4 inches spread	7.0
14	36.72	2 inches below, 6 inches by 6 inches spread	7.5

Field fertilizer studies—row methods

This study of the various locations of fertilizer along the seed row, was made at the Agronomy Farm. Each row (except the checks) consisted of 6 fertilized treatments with increasing rates of application. The Ammo-Phos plus KCl was again used, the treatments being 16 feet long and having 50 corn kernels each. Border rows were run on all sides of the test. Table 10 gives the plan of the test with the final immature harvest weights. Weights were taken at one earlier date but the results are omitted as they were quite similar. Fifteen plants were harvested on each date.

A depression in germination for all of the *below* fertilized rows was noted, no. 4 being more retarded than no. 3 because of the narrow spread of the fertilizer located *1 inch below* the seed at the planting. All of the *above* fertilized rows evidenced good growth, since rains occurred to leach the soluble salts down around the roots but not soon enough after planting to

injure the germination. Six days after the test was started, 1.15 inches of rain fell, followed five days later by 1.25 inches.

All of the *side* treatments gave good growth throughout the season with no retardation of germination and no depression of early growth. If the season had been dry, however, the *above* fertilized rows would undoubtedly have failed to give as good response. The great solubility of the fertilizer

TABLE 10

Field study of row methods of applying fertilizer

ROW NUMBER	FERTILIZER LOCATIONS RELATIVE TO SEED ROW	FINAL GERMINATION COUNTS: For fertilizer rates of 100 pounds	200 pounds	400 pounds	FINAL HARVEST WEIGHTS: For fertilizer rates of 100 pounds	200 pounds	400 pounds
					pounds	*pounds*	*pounds*
1	Check—unfertilized	48	49	50	4.7	5.0	4.1
2	2 inches below, narrow spread	49	50	39	9.0	11.0	12.4
3	1 inch below, wide spread	48	47	37	11.5	12.6	13.0
4	1 inch below, narrow spread	49	44	31	10.0	10.7	11.0
5	1 inch above, narrow spread	50	49	42	10.7	11.5	12.5
6	1 inch above, wide spread	50	49	46	11.4	11.8	12.7
7	1 inch above, split as with "deflectors"	48	47	50	11.0	12.4	13.0
8	Check—unfertilized	49	50	49	4.9	5.5	3.9
9	Both sides, 1 inch away, narrow spread, same plane	49	49	50	12.0	12.6	13.3
10	Both sides, 1 inch away, wide spread, same plane	48	50	48	10.8	11.5	12.5
11	Both sides, 1 inch away, narrow spread, lower plane	47	48	49	10.5	11.0	12.1
12	One side, 1 inch away, narrow spread, lower plane	50	48	46	10.4	10.8	11.5
13	One side, 1 inch away, narrow spread, same plane	50	48	47	11.5	11.5	12.0
14	One side, 1 inch away, wide spread, same plane	49	50	49	10.7	10.5	11.0
15	Mixed with soil in seed row	47	42	27	9.0	10.3	7.5*
16	Check—unfertilized	50	48	49	5.2	6.4	5.5
17	Direct contact with seed in row	30	7	0	6.4	1.5†	None

* [illegible]

† Two plants harvested.

mixture aided the *above* rows tremendously too. The data in the table again show the bad effects of high applications of concentrated, readily-soluble chemical fertilizers distributed *direct contact in the seed rows* or *mixed with the soil in the seed row.*

Root growth study

In the root growth study, corn was planted in the center of wire baskets in 4-gallon pots containing a loam and allowed to grow with the roots inter-

twining with the mesh of crosswires of the baskets. Hence, the roots were retained in their normal growth directions after the supporting soil had been washed away. Various locations of the commercial 2–12–2 relative to the hills were then made at the rate of 200 pounds per acre and different methods of watering the pots were followed.

A decided outward growth of the roots was found in all of the baskets where the fertilizer zone was located directly *below the hill*. This tendency was greater in the capillary watered pots than in the surface watered ones. The high concentration of the salts probably explains the negative growth

TABLE 11

Series I: Greenhouse study of phosphorus movement in a loam soil with irregular surface watering of the boxes

BOX NUMBER AND FERTILIZER TREATMENT	LOCATION OF SAMPLES	AVERAGE TOTAL PHOSPHORUS IN SOIL	BOX NUMBER AND FERTILIZER TREATMENT	LOCATION OF SAMPLES	AVERAGE TOTAL PHOSPHORUS IN SOIL
		per cent			*per cent*
1. (0–16–0), rear of hill	Above	0.134	6. (3–12–3), rear of hill	Above	0.137
	Below	0.334		Below	0.217
	Sides	0.131		Sides	0.125
2. (0–16–0), broadcast	Surface soil	0.260	7. (3–12–3), broadcast	Surface soil	0.195
	Subsoil	0.137		Subsoil	0.137
3. (0–16–0), 1 inch below hill	Above	0.133	8. (3–12–3), 1 inch below hill	Above	0.134
	Below	0.283		Below	0.195
	Sides	0.137		Sides	0.129
4. (0–16–0), 1 inch above hill	Above	0.139	9. (3–12–3), 1 inch above hill	Above	0.145
	Below	0.318		Below	0.276
	Sides	0.135		Sides	0.126
5. (0–16–0), sides of hill	Above	0.134	10 (3–12–3), sides of hill	Above	0.135
	Below	0.375		Below	0.197
	Sides	0.137		Sides	0.130

movement. With applications of acid phosphate located *below the hill*, no injurious root growths were found and only a stimulated development appeared. The tendency toward restriction and negative movement seems to be associated with the concentrated soluble chemical fertilizers and occurs primarily during the first few days of the seedling growth.

Fertilizer diffusion studies

Two series of fertilizer diffusion studies were run in the greenhouse. The first one was conducted with 10 cropped boxes and the second one with 6 uncropped boxes. Various hill locations of acid phosphate and a complete 3–12–3 fertilizer were employed in the different boxes at 300 pounds per

acre, but with the same kind of hill location in all of the compartments of a given box. The cropped boxes grew corn. All of the boxes in the first series were surface watered, but in the second series 2 soil types and 3 systems of watering were used. The general outlines of the series are shown in tables 11 and 12, which also give the results.

The soil samples on which these tests were made, were secured 1, 2, 3, 4, 6, 8, 10 and 12 weeks after starting the studies in series I, and 4, 11, 18, 25, 32,

TABLE 12

Series II: Effects of soil type and methods of watering the boxes upon phosphorus diffusion

BOX NUMBER AND SOIL TYPE	METHOD OF WATERING THE BOXES	LOCATION OF SOIL SAMPLES RELATIVE TO FERTILIZERS	AVERAGE TOTAL PHOSPHORUS IN SOIL	AVERAGE TOTAL NITROGEN IN SOIL
			per cent	*per cent*
1. Webster loam	Surface	Above	0.094	0.420
		Below	0.418	0.559
		Sides	0.099	0.410
2. Webster loam	Combination	Above	0.099	0.435
		Below	0.163	0.467
		Sides	0.104	0.408
3. Webster loam	Capillary	Above	0.171	0.443
		Below	0.126	0.425
		Sides	0.100	0.415
4. Miami silt loam	Surface	Above	0.075	0.240
		Below	0.294	0.316
		Sides	0.072	0.233
5. Miami silt loam	Combination	Above	0.107	0.254
		Below	0.178	0.295
		Sides	0.093	0.241
6. Miami silt loam	Capillary	Above	0.194	0.268
		Below	0.095	0.247
		Sides	0.089	0.235

39, 46 and 53 days after, in series II. They were taken from a new compartment in each box and in definite locations relative to the respective fertilizer zones. Only the average results are given. In the broadcast boxes, only two samples were taken, one from the surface soil, the other from the subsoil which received no fertilizer. In all the hill fertilized boxes, three soil samples were taken as follows:

(*a*) The soil layer from ½ to 1½ inches directly above the fertilizer zone; (b) the same soil layer directly below the zone; and (*c*) the soil on all sides of the fertilizer zone from ½ to 1½ inches away horizontally.

A study of the tables shows the following facts:

(*a*) The soluble phosphorus fertilizer moved downward with the surface watering. (*b*) Likewise, it moved upward with the capillary watering. (*c*) The downward leaching movement was more pronounced than the upward capillary movement. (*d*) The most rapid and the greatest movement took place in the *above the hill* fertilized boxes. (*e*) The least rapid and weakest movement occurred in the *below the hill* fertilized boxes. (*f*) The larger part of this movement took place immediately following the starting of the studies. In fact, the maximum was frequently indicated for the soil sampled first, with a gradual decline in the percentage found in the later samples. (*g*) The movement of nitrogen was found to be similar to that of phosphorus. (*h*) At least half or more of the original fertilizer applications remained at the conclusion of the studies in their respective zones. This fertilizer appeared granular and identical with the original material, only of course the soluble salts had been largely leached away.

CONCLUSIONS

A general study of the data presented shows first of all that fertilizer applications located *direct contact in the hill* or *direct contact in the drill-row* with seed are likely to be very injurious to the best germination of the seed. Various factors, such as rainfall, soil type, kind of seed, and kind of fertilizer obviously modify the injury obtained. Very small amounts of concentrated, readily-soluble chemical fertilizers are injurious, and these amounts are often smaller than the rates for which the fertilizer attachments upon the present day seeding machines are capable of adjustment.

The low applications of fertilizers give retarded germination, but the high ones cause inhibition of germination. The injury increases directly with the fertilizer application. Therefore, for the best germination of all seeds under all conditions of climate and soil, the distribution of fertilizers *direct contact* either in the hill or in the row with the seed is not advised. Those planters with fertilizer attachments so designed, either to cause or to permit this *direct contact* application of the fertilizer should certainly be redesigned.

In place of the *direct contact* method of fertilizer application, there are several other methods of localized distribution. The *above the hill or drill-row*, the *below the hill or drill-row*, and the *sides of hill or drill-row* methods seem most promising. Because of a direct dependence of the first two methods upon climatic conditions and other variable factors, the *above* and the *below* locations are felt to be unwise. Therefore, the *sides* method of fertilizer distribution remains as the best solution of the problem for all crops sown in hills or rows with wide intervals between the successive rows. Horizontal diffusion of salts is very slow, and hence the *sides* method proves safe to germination. Then too, the fertilizer is located in the immediate proximity of the young seedling's branching roots to furnish immediately sufficient plant-food to permit of a good crop yield and early maturity.

As another possible method of such localized fertilizer distribution—a method which is certainly better than the *direct contact* location but not entirely free of dangers to germination—the *mixed with the soil in the hill or*

drill-row method is suggested. From the standpoint of localized fertilization to promote the best growth, this method should be almost ideal. However, with very high applications of concentrated, readily-soluble chemical fertilizers, the method will cause marked germination injury. As long as moderate amounts of non-caustic fertilizers are applied by this method through an efficient attachment, good results should be secured. If the limitations of the method could be accurately understood by all parties concerned and if farmers would be willing to split their large fertilizer applications between localized and broadcast methods, then the ***mixed in the row*** method might be considered satisfactory. Under the existing conditions, however, the *sides* method alone is recommended for localized fertilizer applications.

POTASSIUM FERROCYANIDE AND FERRIC FERROCYANIDE AS SOURCES OF IRON FOR PLANTS

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In search of a compound that would furnish iron satisfactorily to plants grown in weakly acid or slightly alkaline nutrient solutions a number of experiments were performed with potassium ferrocyanide and ferric ferrocyanide.[1] Potassium ferrocyanide is unique as an iron source because it contains iron in the anion. Ferric ferrocyanide, or Prussian blue, contains iron in both the cation and anion and is relatively insoluble in water. These complex iron salts were found to be fair sources of iron for green plants under rather limited conditions. With potassium ferrocyanide the chief condition was to secure a low enough concentration of the salt to escape its toxic effects, whereas with ferric ferrocyanide the reaction of the nutrient solution was the chief factor determining the availability of the iron.

Knop (1) in 1869 found that chlorotic corn plants became green when supplied with potassium ferrocyanide at the rate of 0.1 per mille (13.22 p.p.m. of iron) but that the growth of the plants was slowed and finally stopped. Wagner (8) in the following year confirmed the results of Knop and observed a slight deposit of ferric ferrocyanide on the roots. Susuki (5) observed a poisonous action on barley seedlings of potassium ferrocyanide at a concentration of 0.01 per mille (1.322 p.p.m. of iron) in water cultures. In soil cultures (6) it stimulated growth. He ascribed the poisonous action to hydrocyanic acid, which was formed within the plant by the splitting of the potassium ferrocyanide, but was unable to decide whether the stimulating action in the soil was due to the compound itself or to its decomposition products. Loew and Kozai (2) observed a stimulating effect of 0.01 per cent potassium ferrocyanide on *Bacillus prodigiosus* but no improvement in the growth of other bacteria. No reference to the use of ferric ferrocyanide as a source of iron for plants was found in the literature.

EXPERIMENTAL

Spirodela polyrhiza (L.) Schleid. plants, floating aquatics, were grown in Knop's nutrient solution diluted 10 times in accordance with the findings of Saeger (4). Iron was added to the solution in the forms of ferric citrate,

[1] The author wishes to acknowledge his thanks to Dr. W. J. Robbins for helpful criticism and advice in the course of this investigation.

ferrous sulfate, ferric chloride and potassium ferrocyanide at the concentrations indicated in table 1. To one solution no iron was added.

The three commonly used iron salts: ferric citrate, ferrous sulfate, and ferric chloride produced a very satisfactory growth of these plants, the largest growth being secured with ferrous sulfate as is shown in table 1. The leaves of the plants in the solution containing the lowest concentration of iron as potassium ferrocyanide (0.016 p.p.m. iron) were small and chlorotic. The plants in the solutions containing 0.033 and 0.066 p.p.m. iron as potassium ferrocyanide made fair growth but the leaves were a trifle lighter green than those of plants in the solutions containing the commonly used iron salts.

TABLE I

Growth data of Spirodela plants grown 23 days in Knop's solution containing iron in the salts as the concentrations indicated. *

IRON SALT	CONCENTRATION OF IRON	AVERAGE NUMBER MATURE LEAVES PER CULTURE†	AVERAGE GREEN WEIGHT PLANTS PER CULTURE	REACTION OF SOLUTIONS	
				Initial	Maximum final
	p.p.m.		*mgm.*	*pH*	*pH*
Check	0.000	18.25	37.00	6.6	7.4
Fe citrate	2.280	152.25	513.75	6.4	7.3
$FeSO_4$	3.676	160.75	563.75	6.5	7.1
$FeCl_3$	2.065	137.25	527.00	6.2	7.0
$K_4Fe(CN)_6$	0.016	62.00	140.00	6.7	7.4
	0.033	102.00	275.00	6.7	7.6
	0.066	93.50	308.75	6.7	7.6
	0.132	78.50	267.25	6.7	7.7
	0.264	53.50	171.25	6.6	7.5

* The nutrient solutions were renewed 5 times at intervals of 4 days.

† Average of 4 cultures.

With the highest concentrations of iron as potassium ferrocyanide (0.132 and 0.264 p.p.m. iron) the leaves of the plants were normal green but the growth of the plants with the latter concentration was greatly reduced. The plants in the solution without iron made very poor growth and the leaves were chlorotic.

With soybean plants concentrations of 0.264 p.p.m. and higher of iron in the form of potassium ferrocyanide greatly depressed growth. Concentrations of 0.033 and 0.066 p.p.m. iron in this iron salt produced fair growth of soybean plants, but chlorophyll development was not adequately provided for, the leaves being light green.

Potassium ferrocyanide was used in solutions having reactions from pH 3.1 to 8.3. *Spirodela* plants grew best at pH 6.2 and 6.8. This iron salt was not so satisfactory at neutral and slightly alkaline reactions as ferric citrate.

Merck's iron ferrocyanide used at concentrations of 0.022 to 9.0 p.p.m. iron per liter in Knop's solution resulted in very poor growth and chlorosis of the

foliage of soybean and *Spirodela* plants. The explanation of these results was found when this iron salt was used in a series of buffered solutions having reactions of pH 4.0 to 8.3. Knop's solution was modified by omitting KNO_3, substituting H_3PO_4 at the rate of 0.8055 gm. per liter for KH_2PO_4, and adding potassium acid phthalate at the rate of 1.0207 gm. per liter. These changes were based on the buffered nutrient solution developed by Tarr and Noble (7). At pH 5.0 soybean plants made a greater growth when the solution contained ferric ferrocyanide than when it contained ferric citrate, the iron contents of both solutions being the same (5 p.p.m. iron). At pH 5.5 the foliage of the plants in the solution containing ferric ferrocyanide was light green and at all higher reactions it was distinctly chlorotic. The plants in the solutions con-

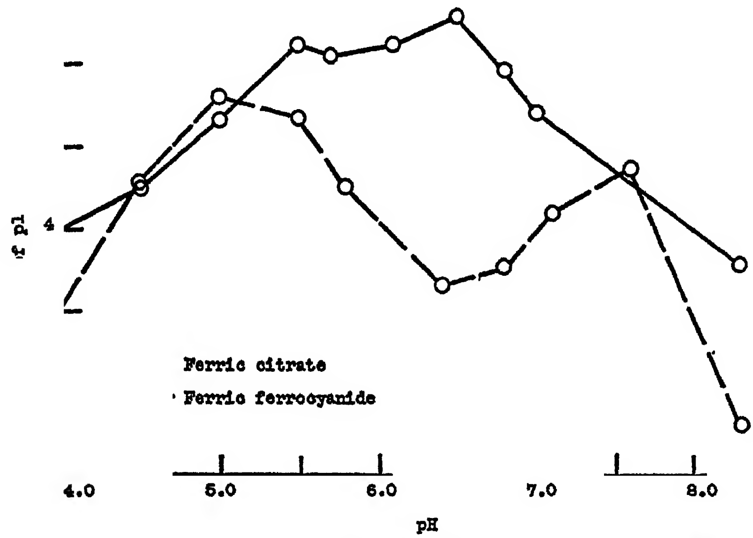

FIG. 1. GREEN WEIGHT OF SOYBEAN PLANTS FOR EACH CULTURE IN NUTRIENT SOLUTIONS CONTAINING 5 P.P.M. IRON AS FERRIC CITRATE AND FERRIC FERROCYANIDE

taining ferric citrate made very satisfactory growth from pH 5.5 to 6.5, but from pH 6.8 to 8.3 the leaves of the plants were chlorotic.

The reaction of Knop's solution as used for soybeans in the earlier experiments was pH 5.8 and when diluted 10 times for *Spirodela* plants, pH 6.6. Both of these reactions were in the region in which the iron of ferric ferrocyanide in the above experiment was insufficiently available for the normal growth of soybean plants.

The growth curve (fig. 1) of the soybean plants grown in the buffered nutrient solutions containing ferric ferrocyanide shows two maxima, one occurring at pH 5.0 and a second at pH 7.6 with a marked depression in growth around pH 6.4. It is of interest to note that Robbins and Scott (3) found the isoelectric point of soybean root tips to be in the vicinity of pH 6.4.

SUMMARY

1. With 0.033 and 0.066 p.p.m. iron in the form of potassium ferrocyanide, soybean and *Spirodela polyrhiza* plants made fair growth. Higher concentrations of iron in this salt produced a slow stoppage of growth.

2. Merck's ferric ferrocyanide was a satisfactory source of iron for soybean plants when the solution had a reaction of pH 5.0 but at less acid reactions growth of the plants and chlorophyll development was restricted.

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THE VIABILITY OF THE NODULE BACTERIA OF LEGUMES OUTSIDE OF THE PLANT: I, II[1]

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INTRODUCTION

The success or failure of the process of inoculation depends upon the viability of the nodule bacteria of legumes outside of the plant. There are many factors which must be taken into consideration in connection with the life or death of the nodule bacteria when removed from their host plant. Some of the important factors controlling their active resistance have been studied from time to time by various investigators. It still remains true, however, that perfectly viable pure cultures are applied to seeds, and an insufficient number of the organisms remain alive on the seed to give satisfactory inoculation before the seed is planted and, in some cases, after the seed has been planted.

Soil inoculation also fails under conditions which can be accounted for in part on the basis of certain important factors which are included in this study. Because of the very common failure of commercial cultures and of the occasional failures of pure cultures put out by experiment station workers, a study of the fundamental factors responsible for the life of the organisms under the conditions to which the seed must be subjected was considered as the first and most important step in the solution of the problem of successful inoculation.

Certain clean-cut, positive data regarding the organism and its growth under proved conditions have been accepted as a basis upon which to build the foundation for this experimental work. A great deal of work irrelevant to the real factors concerned in a successful carrying out of this process has been published in connection with the inoculation problem. The work of Löhnis, Burrill, Whiting, Hansen, Bewley and Hutchinson, Fred, Shunk, and their associates made it possible to outline definite studies dealing with the factors concerned in the viability of the nodule bacteria outside of the plant. The work of Whiting and associates (14) with nodule bacteria covers a decade and

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the writer had gathered the salient points in this experience for attacking this problem. Especially is the work of Löhnis and Smith (10) on the life cycles of bacteria, Löhnis and Hansen (9), and Bewley and Hutchinson (2) pertinent to this investigation.

In some cases, determinations have been made that are repetitions of work found in the literature. These have been made a part of these investigations because it was necessary to establish definitely many points related to the facts brought out by the above workers.

Data for nodule production as influenced by time of storage, temperature during storage, kind of container for storage, maintenance of the organisms in pure and impure cultures in association with other nitrogen-fixing bacteria, with yeasts, molds, and with non-nitrogen-fixing bacteria on and in different media; the effect of different treatments such as the reinforcing of the inoculation with sugar, glue, and soil in various combinations and in different concentrations; the effect of calcium carbonate, tricalcium phosphate, and sugar in various amounts with soil, constitute the first part of this study. The effect of sunlight, dessication, and aeration were investigated. Extensive studies were conducted as to the effect of time and dilution upon the number of the legume organisms surviving when cultured in liquid media; the effect of limited and ample quantities of oxygen upon the life of the organism grown both in liquid and in solid media; and the comparative effect of cane sugar and mannite, both in solid and in liquid media, upon the life of the legume organisms. The effect of acidity in the soil on the infective power of nodule bacteria was studied. Thermal death point determinations were made without reference to previous determinations.

The solution of these problems is dependent in part upon a knowledge of the life cycle of the organisms, and with this in view, the last part of this investigation was devoted to extensive experiments concerning the life cycle of nodule bacteria as influenced by certain chemicals.

HISTORICAL

Beijerinck (1) in 1887 first isolated in pure culture from the nodules of legumes, an organism which he described as *Bacillus radicola.* The description given by Beijerinck represents a fairly accurate description of the nodule bacteria as they are now recognized.

Burrill and Hansen (3) in 1917 proved that the organisms producing nodules on cowpeas and soybeans were typical of *Pseudomonas*, and the name *Pseudomonas radicicola* was properly used by them in describing the organisms concerned with those legumes.

Löhnis and Hansen (9) produced a convenient and well adapted method which greatly assists in proving the purity of the legume cultures.

Hopkins and Burrill (7), Whiting and Hansen (14), and Whiting and others have worked out a number of groups of cross-inoculations and have accumulated a large number of data dealing with the factors responsible for suc-

cessful inoculation. The information obtained by these workers has been available in connection with the present study.

Fred and Davenport (6) have determined the pH values for a number of legume bacteria and Azotobacter, and these values have been found useful in connection with this work.

Shunk (12), working at the North Carolina experiment station, has succeeded in making flagella stains of nodule bacteria from 41 species of legumes. His work is in practically complete agreement with the work published from the Illinois experiment station, and furnishes an important contribution toward the clearing up of the whole question of the flagellation of nodule bacteria and the question of whether there are two organisms concerned in nodule production.

Certain references related to the study of the life cycle of nodule bacteria will be considered under part V of this paper.

PART I—EXPERIMENTS ON THE ENDURANCE OF NODULE BACTERIA IN SOIL AND ON SEED AS INFLUENCED BY VARIOUS TREATMENTS AND TIME OF STORAGE BEFORE AND AFTER INOCULATION

Methods Employed

The cultures used were obtained from the pure stock cultures of Doctor A. L. Whiting. Many of the cultures from which the infusions were made were grown in 8-ounce glass bottles. Unless otherwise stated, it is to be understood that only pure cultures of the nodule bacteria were employed in these experiments.

Soybeans, sweet clover, garden peas (wrinkled and smooth), and cowpeas were used in these experiments. The seeds were sterilized in a solution of mercuric chloride (1 to 500) for 10 minutes, after which they were washed with sterile distilled water at least fourteen times, then dried.

Clean quartz sand was placed in pint glass fruit jars and the whole sterilized for several hours in a hot air oven at 350°C. After the jars were cooled and well aerated, 1 gm. of pure calcium carbonate was added to each. The moisture content of the sand was maintained at about 14 to 16 per cent. Usually 7 of the larger seeds and 25 to 30 of the smaller seeds were planted in each jar. The jars, carefully covered with wrapping paper, were left in the laboratory until the seeds had germinated. Then they were kept in the greenhouse until washed out for nodule examination. Plant-food elements with the exception of nitrogen, were applied to all the plants in all the experiments a number of times depending upon the duration of the experiment.

An examination for the presence of nodules was made usually after the peas were 20 days old. The development of nodules varied considerably for different plants; for example, the Alaska peas (smooth), developed nodules in 12 days, whereas the late peas (wrinkled) failed to develop nodules much before

20 to 27 days. An abnormal growth was often found to retard the appearance of nodules.

The data on nodule production are classified as many, few, and none.

Experiment 1—The Effect of the Addition to the Nodule Infusion of Soil, Glue, and Sugar in Different Combinations on the Length of Time the Organisms Survive on the Seed

The purpose of this experiment was to test the length of time that the nodule organisms would survive in sufficient numbers for successful inoculation when applied to the seed as an infusion made with either distilled or tap water. Additions of soil; glue; and soil and glue; sugar; sugar and soil; and sugar, glue, and soil were made to the bacterial infusion and these mixtures applied to the seed. The amounts of the various materials used in making these mixtures are given in table 1.

TABLE 1

Additions made to bacterial infusion in experiment 1

	TREATMENT
1	Bacterial infusion
2	Bacterial infusion + 30 gm. air-dried brown silt loam
3	Bacterial infusion + 15 cc. of glue solution (60 gm. glue for each liter of water.)
4	Bacterial infusion + 30 gm. of soil + 15 cc. of glue solution
5	Bacterial infusion +7 gm. cane sugar
6	Bacterial infusion + 30 gm. soil + 7 gm. cane sugar
7	Bacterial infusion + 30 gm. soil + 15 cc. glue + 7 gm. cane sugar

Each lot of seed weighed 2 pounds and received the bacterial infusion on the basis of 1 bottle for each bushel of seed. The bacterial infusion was applied to 14 pounds of seed, which was thoroughly mixed and divided into 7 lots. Caution was exercised to mix thoroughly all of the various additions with the seeds. Treated lots were dried in enameled pans and then transferred to ordinary cloth seed bags and stored in a locker in the laboratory. After 1 month, each lot was divided into 2 parts, one part being left in the cloth bags and the other part placed in glass fruit-jars with tight tops. The jars were stored in the locker, whereas the bags were stored in the laboratory store room. The humidity and temperature conditions were approximately the same in both places.

In this first experiment, soybeans, sweet clover, and wrinkled garden peas were used. The soybeans were inoculated October 7, the sweet clover, October 9, and the wrinkled peas, October 18, 1920. Duplicate jars of each treatment were planted immediately and after various intervals, as shown in table 2.

The results from all the series of soybeans, sweet clover, and garden peas in this experiment as reported in tables 1, 2, and 3 show that nodule production

was fairly consistent, regardless of conditions and kind of treatment. The number of nodules produced from all treatments would appear to be ample for the fixation of nitrogen for normal growth. As an average, 12 were found on each plant at the various stages. The time of storage after inoculation, up to 2 months, did not materially influence nodule production. Depressions were seen here and there, but in no cases were they important. In such cases, it is believed that uneven distribution of the organisms occurred. This is shown where one lot developed a few nodules at the immediate planting, but developed many nodules at the later plantings. The number of times the seed was mixed would account for certain of these fluctuations.

The treatments containing sugar showed a nodule production superior to the treatments containing soil or glue. With sugar treatments the nodules were uniformly large and evenly distributed over the root system. Besides, the nodule production was fairly consistent through all the plantings (24 hours, 36 hours, 48 hours, 72 hours, 2 weeks, 1 month, and 2 months). The stimulative

TABLE 2

Series and intervals of planting

INTERVALS OF PLANTING	SERIES		
	Soybean	Sweet clover	Garden peas
Immediately after inoculation	100	1,000	2,080
24 hours after inoculation	200	1,010	2,090
36 hours after inoculation	300	1,020	2,300
48 hours after inoculation	400	2,030	2,310
72 hours after inoculation	500	2,040	2,320
2 weeks after inoculation	600	2,050	2,330
1 month after inoculation	700	2,060	2,340
2 months after inoculation	900	2,070	2,350

action of sugar is probably due to its supplying energy upon which the organisms feed when put under favorable conditions. Sugar possesses the characteristic of gathering moisture from the air, thereby creating on the seed-coat, a film which serves as a protection against the harmful effect of desiccation. Although Clerk (4) stated that moisture has none, or very little effect on the viability of the organisms, yet he failed to show whether its absence is harmful to the organisms under storage conditions. The thin film of moisture on the inoculated seeds treated with sugar, may permit the organisms to move through and distribute themselves more evenly on the seeds.

Soil used with the bacterial infusion was found to be beneficial. The soil particles may serve as a protection for the organisms against desiccation, because of the film of moisture around the soil particles. Soil contains food which helps to prolong the life of the bacteria.

Glue with the bacterial infusion was of very little benefit although it was not found harmful to the legume organisms. Magon and Dana (11) reported that

TABLE 3

Effect of different treatments on the production of nodules on soybeans

	TREATMENT							
	Uninoculated	Bacterial infusion	Bacterial infusion + soil	Bacterial infusion + glue	Bacterial infusion + soil + glue	Bacterial infusion + sugar	Bacterial infusion + sugar + soil	Bacterial infusion + sugar + soil + glue
Series 100—Planted immediately after inoculation (plants 25 days old)								
Number of plants	7	7	7	7	7	6	6	7
Plants with nodules	None	7	7	7	5	6	6	6
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	Many	Many	Many	Many	Many	Many	Many
Series 200—Planted 24 hours after inoculation (plants 25 days old)								
Number of plants	7	5	5	7	7	7	6	7
Plants with nodules	None	5	5	7	7	7	5	6
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	Many	Many	Many	Many	Many	Many	Many
Series 300—Planted 36 hours after inoculation (plants 23 days old)								
Number of plants	4	4	4	5	5	4	3	4
Plants with nodules	None	4	4	5	5	4	3	4
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	Many	Many	Many	Many	Many	Few	Many

Series 400—Planted 48 hours after inoculation (plants 23 days old)

Number of plants	4	2	4	4	5	6	4	7
Plants with nodules	None	2	3	4	5	6	4	7
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	Few	Few	Few	Many	Many	Many	Many

Series 500—Planted 72 hours after inoculation (plants 20 days old)

Number of plants	7	5	5	4	6	7	6	6
Plants with nodules	None	4	4	3	6	7	6	6
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	Many	Many	Many	Many	Many	Many	Many

Series 600—Planted 2 weeks after inoculation (plants 24 days old)

Number of plants	7	7	6	7	Died	5	5	5
Plants with nodules	None	7	6	6	Died	5	5	5
Nodule record:								
Size number	None	Small	Medium	Medium	Died	Large	Large	Large
Number	None	Many	Many	Many	Died	Many	Many	Many

Series 700—Planted 1 month after inoculation (plants 26 days old)

Number of plants	4	7	6	5	5	6	5	6
Plants with nodules	None	7	5	5	5	6	5	5
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	Many	Many	Many	Many	Many	Many	Many

Series 900—Planted 2 months after inoculation (plants 30 days old)

Number of plants	4	5	6	5	6	6	6	6
Plants with nodules	None	4	6	3	5	6	3	5
Nodule record:								
Size	None	Medium	Medium	Medium	Medium	Large	Large	Large
Number	None	Many	Many	Few	Many	Many	Many	Many

TABLE 4

Effect of different treatments on the production of nodules on sweet clover

	TREATMENT							
	Uninoculated	Bacterial infusion	Bacterial infusion + soil	Bacterial infusion + glue	Bacterial infusion + soil + glue	Bacterial infusion + sugar	Bacterial infusion + sugar + soil	Bacterial infusion + sugar + soil + glue
Series 1000—Planted immediately after inoculation (plants 45 days old)								
Number of plants	4	7	4	4	5	7	5	3
Plants with nodules	None	7	4	4	5	7	5	3
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	Many	Many	Many	Many	Many	Many	Many
Series 1010—Planted 24 hours after inoculation (plants 44 days old)								
Number of plants	7	6	4	7	5	4	5	7
Plants with nodules	None	6	4	7	5	4	5	7
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	None	Few	Few	Few	Many	Many	Many
Series 1020—Planted 36 hours after inoculation (plants 44 days old)								
Number of plants	4	7	6	2	7	5	6	6
Plants with nodules	None	7	6	2	7	5	6	4
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Medium	Large	Large
Number	None	Few	Few	Few	Many	Many	Many	Many

Series 2030—Planted 48 hours after inoculation (plants 43 days old)

Number of plants	5	5	1	4	4	7	7	4
Plants with nodules	None	5	1	4	4	7	7	4
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	Few	Few	Few	Few	Many	Many	Few

Series 2040—Planted 72 hours after inoculation (Plants 42 days old)

Number of plants	4	4	6	5	3	7	6	7
Plants with nodules	None	4	6	5	3	7	6	7
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	Few	Few	Few	Few	Many	Many	Many

Series 2050—Planted 2 weeks after inoculation (plants 28 days old)

Number of plants	7	4	Died	7	6	7	7	7
Plants with nodules	None	1	Died	7	6	7	7	7
Nodule record:								
Size	None	Small	Died	Small	Small	Medium	Medium	Medium
Number	None	1	Died	Few	Few	Few	Many	Many

Series 2060—Planted 1 month after inoculation (plants 35 days old)

Number of plants	5	5	5	7	4	7	5	7
Plants with nodules	None	5	4	7	4	7	5	7
Nodule record:								
Size	None	Small	Small	Small	Small	Large	Large	Large
Number	None	Few	Few	Few	Few	Many	Many	Many

Series 2070—Planted 2 months after inoculation (plants 52 days old)

Number of plants	2	3	7	7	7	1	2	3
Plants with nodules	None	3	7	7	7	1	2	3
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Medium	Medium	Medium
Number	None	Few	Few	Few	Few	Few	Few	Many

TABLE 5

Effect of different treatments on the production of nodules on garden peas

	TREATMENT							
	Uninoculated	Bacterial infusion	Bacterial infusion + soil	Bacterial infusion + glue	Bacterial infusion + soil + glue	Bacterial infusion + sugar	Bacterial infusion + sugar + soil	Bacterial infusion + sugar + soil + glue
Series 2080—Planted immediately after inoculation (plants 30 days old)								
Number of plants	6	5	5	4	7	6	7	7
Plants with nodules	None	4	5	4	7	6	7	7
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	Many	Many	Many	Many	Many	Many	Many
Series 2090—Planted 24 hours after inoculation (plants 30 days old)								
Number of plants	7	5	5	5	7	4	7	6
Plants with nodules	None	5	5	5	7	4	7	6
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	Few	Few	Many	Many	Many	Many	Many
Series 2300—Planted 36 hours after inoculation (plants 29 days old)								
Number of plants	5	6	7	7	7	7	7	7
Plants with nodules	None	6	7	7	7	7	7	7
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	Many	Many	Many	Many	Many	Many	Many

Series 2310—Planted 48 hours after inoculation (plants 28 days old)

Number of plants	5	6	6	7	5	4	5	6
Plants with nodules	None	6	6	7	5	4	5	6
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	Few	Many	Many	Many	Many	Many	Many

Series 2320—Planted 72 hours after inoculation (plants 27 days old)

Number of plants	7	7	7	5	6	5	7	Died
Plants with nodules	None	7	7	5	6	5	7	Died
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Died
Number	None	Few	Many	Few	Many	Many	Many	Died

Series 2330—Planted 2 weeks after inoculation (plants 31 days old)

Number of plants	6	6	7	5	6	4	6	4
Plants with nodules	None	1	4	3	5	4	4	4
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	Few	Few	Few	Few	Few	Many	Many

Series 2340—Planted 1 month after inoculation (plants 31 days old)

Number of plants	7	7	6	7	6	7	7	7
Plants with nodules	None	7	6	7	6	7	7	7
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	Many	Many	Many	Few	Many	Many	Many

Series 2350—Planted 2 months after inoculation (plants 28 days old)

Number of plants	4	3	5	5	6	5	6	6
Plants with nodules	None	3	5	5	6	5	6	6
Nodule record:								
Size	None	Small	Medium	Medium	Medium	Large	Large	Large
Number	None	Few	Many	Many	Many	Many	Many	Many

the use of glue with the bacterial infusion was injurious because it was heavily infected with different kinds of bacteria. The fact that the nodule production in the treatment containing bacterial infusion and glue was superior to the untreated bacterial infusion in this experiment, was probably due to the fact that the seeds were twice mixed in applying both the glue and the bacterial infusion. Fellers (5) reported that the use of glue with the bacterial infusion gave no benefit, but, rather, was injurious to the legume organisms, as it contained different kinds of bacteria.

TABLE 6

Additions made to bacterial infusion in experiment 2

LOT	TREATMENT
1	5 cc. bacterial infusion
2	5 cc. bacterial infusion + 7 gm. cane sugar
3	5 cc. bacterial infusion + 30 gm. air-dried brown silt loam
4	7 gm. cane sugar dissolved in 5 cc. bacterial infusion
5	30 gm. air-dried brown silt loam + 7 gm. cane sugar dissolved in 5 cc. bacterial infusion
6	30 gm. air-dried brown silt loam mixed with 5 cc. bacterial infusion

TABLE 7

Series and intervals of planting

INTERVALS OF PLANTING	GARDEN PEAS	
	Series A—wrinkled	Series B—smooth
5 days after inoculation	2,360	2,400
15 days after inoculation	2,370	2,410
20 days after inoculation	2,380	2,420
30 days after inoculation	2,390	2,430

Experiment 2—The effect upon nodule production of sugar and soil in different combinations with the infusion

The purpose of this experiment was to determine whether sugar and soil, with the infusion in different combinations, would stimulate nodule production sufficiently to be of real value.

The experiment was divided into parts, A and B. In part A, wrinkled garden peas were used, and in part B, smooth garden peas. The same procedure was used for each experiment. Table 6 shows the treatments applied.

Each lot consisted of 1 quart of seed. In all cases, the mixtures that were added were applied to the seed and the seed was thoroughly mixed. It will be seen from table 6 that, in some cases, the sugar and soil were mixed with the infusion before the mixture was applied to the seed, whereas in other cases, the infusion was applied to the seed, and the soil and sugar were applied afterwards.

In lots 4, 5, and 6, the added materials were dissolved in the bacterial infusion

TABLE 8

Effect of different treatments on the production of nodules on wrinkled garden peas

	TREATMENT						
	Uninoculated	Bacterial infusion	Bacterial infusion + sugar	Bacterial infusion + sugar + soil	Sugar + infusion mixed	Sugar + soil + infusion mixed	Soil + infusion mixed
Series 2360—Planted 5 days after inoculation (plants 30 days old)							
Number of plants	4	6	6	6	6	7	7
Plants with nodules	None	5	6	5	6	7	4
Nodule record:							
Size	None	Small	Large	Large	Large	Large	Large
Number	None	Few	Many	Many	Many	Many	Many
Series 2370—Planted 15 days after inoculation (plants 40 days old)							
Number of plants	6	6	5	4	3	6	5
Plants with nodules	None	5	2	4	3	6	5
Nodule record:							
Size	None	Small	Large	Large	Small	Large	Medium
Number	None	Few	Many	Many	Few	Many	Many
Series 2380—Planted 20 days after inoculation (plants 30 days old)							
Number of plants	4	5	4	5	6	3	4
Plants with nodules	None	5	4	5	6	3	4
Nodule record:							
Size	None	Small	Large	Large	Large	Large	Large
Number	None	Few	Many	Many	Many	Many	Many
Series 2390—Planted 30 days after inoculation (plants 29 days old)							
Number of plants	6	4	6	6	5	7	Died
Plants with nodules	None	4	3	6	5	7	Died
Nodule record:							
Size	None	Small	Large	Large	Large	Large	Died
Number	None	Few	Many	Many	Many	Many	Died

TABLE 9

Effect of different treatments on the production of nodules on smooth Alaska peas

	TREATMENT						
	Uninoculated	Bacterial infusion	Bacterial infusion + sugar	Bacterial infusion + sugar + soil	Sugar + infusion mixed	Sugar + soil + infusion mixed	Soil + infusion mixed
Series 2400—Planted 5 days after inoculation (plants 19 days old)							
Number of plants	6	4	4	5	3	4	2
Plants with nodules	None	3	2	5	3	4	2
Nodule record:							
Size	None	Small	Medium	Medium	Medium	Large	Small
Number	None	Many	Many	Many	Many	Many	Few
Series 2410—Planted 15 days after inoculation (plants 31 days old)							
Number of plants	4	5	3	3	4	4	4
Plants with nodules	None	2	3	3	4	4	4
Nodule record:							
Size	None	Small	Large	Large	Large	Large	Large
Number	None	Few	Many	Many	Many	Many	Many
Series 2420—Planted 20 days after inoculation (plants 24 days old)							
Number of plants	5	4	6	5	4	5	5
Plants with nodules	None	4	6	5	4	5	5
Nodule record:							
Size	None	Medium	Large	Large	Large	Large	Large
Number	None	Many	Many	Many	Many	Many	Many
Series 2430—Planted 30 days after inoculation (plants 21 days old)							
Number of plants	5	3	5	5	3	6	3
Plants with nodules	None	3	5	5	3	6	3
Nodule record:							
Size	None	Small	Large	Large	Large	Large	Large
Number	None	Many	Many	Many	Many	Many	Many

before being applied to the seed. After the applications were made, the seeds of all lots were dried in enameled pans and then transferred to cloth seed bags and stored in the laboratory locker.

The results of experiment 2, part A, are reported in table 8. In the untreated bacterial infusion, the nodule production was not constant in all the plantings. The number of nodules produced at 5-days planting was about one-third as great as at 15-days. The 20-days planting produced one-half as many nodules as the 30-days. Numerous nodules were produced on each plant in all the treatments (lots 2, 3, 4, 5, 6), and the nodule production was constant for a given treatment, in all the different plantings.

TABLE 10

Calcium carbonate, tricalcium phosphate, and sugar applied with bacterial infusion in experiment 3

	TREATMENT
1	10 per cent cane sugar + brown silt loam
2	1 per cent cane sugar + brown silt loam
3	0.1 per cent cane sugar + brown silt loam
4	0.01 per cent cane sugar + brown silt loam
5	1 per cent calcium carbonate + gray silt loam on tight clay
6	0.1 per cent calcium carbonate + gray silt loam
7	0.01 per cent calcium carbonate + gray silt loam
8	1 per cent tricalcium phosphate + brown silt loam
9	0.1 per cent tricalcium phosphate + brown silt loum
10	0.01 per cent tricalcium phosphate + brown silt loam

TABLE 11

Intervals of planting

SERIES—PEAS	TIME OF STORAGE OF SOIL BEFORE INOCULATING SEEDS	TIME OF STORAGE OF SEEDS AFTER INOCULATION BUT BEFORE PLANTING
2,480	Inoculated immediately	Planted immediately
2,500	Inoculated immediately	10 days
2,520	Inoculated immediately	20 days
2,540	Inoculated immediately	30 days
2,560	41 days	Planted immediately
2,580	107 days	Planted immediately

The results of part B are reported in table 9. In the lot receiving bacterial infusion alone, the nodules produced were numerous at the 5-, 20-, and 30-days planting, but decreased to one-third as many at 15-days. All the treatments (lots 2, 3, 4, 5, 6) resulted in numerous and constant nodule production in all of the plantings.

The fluctuation in nodule production which was observed in the lot receiving bacterial infusion alone was not found in lots receiving the other treatments. It was noticed that with sugar either applied on moist inoculated seeds or first

TABLE 12

The effect of calcium carbonate, tricalcium phosphate, and sugar in various amounts in soil on the duration of the life of nodule bacteria after being applied to the seed

TREATMENT	Series 2480—planted immediately after inoculation (plants 29 days old)				Series 2500—planted 10 days after inoculation (plants 26 days old)			
	Number of plants	Plants with nodules	Nodule record		Number of plants	Plants with nodules	Nodule record	
			Size	Number			Size	Number
Uninoculated	2	None	None	None	5	None	None	None
Bacterial infusion	4	4	Small	Few	3	3	Medium	Many
Bacterial infusion + soil (B. S. L.)*	5	5	Medium	Many	3	3	Medium	Many
Bacterial infusion + soil (G. S. L.)†	5	5	Medium	Many	2	2	Medium	Many
Bacterial infusion + soil + 10 per cent sugar	2	2	Medium	Few	4	4	Large	Few
Bacterial infusion + soil + 1 per cent sugar	3	3	Medium	Many	2	2	Large	Many
Bacterial infusion + soil + 0.1 per cent sugar	6	6	Medium	Many	4	4	Large	Many
Bacterial infusion + soil + 0.01 per cent sugar	5	5	Large	Many	4	4	Large	Many
Bacterial infusion + soil + 1 per cent $CaCO_3$	5	5	Small	Many	5	5	Large	Many
Bacterial infusion + soil + 0.1 per cent $CaCO_3$	6	5	Medium	Many	3	3	Large	Many
Bacterial infusion + soil + 0.01 per cent $CaCO_3$	3	3	Medium	Few	4	4	Large	Many
Bacterial infusion + soil + 1 per cent $Ca_3(PO_4)_2$	4	4	Large	Many	5	5	Large	Many
Bacterial infusion + soil + 0.1 per cent $Ca_3(PO_4)_2$	7	7	Large	Many	3	3	Large	Many
Bacterial infusion + soil + 0.01 per cent $Ca_3(PO_4)_2$	6	6	Large	Many	5	5	Large	Many
Bacterial infusion + soil + 0.1 per cent each $Ca_3(PO_4)_2$ + sugar + $CaCO_3$	4	4	Large	Many	2	2	Medium	Many
Bacterial infusion + soil (B. S. L.)* + 0.1 per cent $CaCO_3$	5	5	Large	Many	Died	Died	Died	Died

	SERIES 2520—PLANTED 20 DAYS AFTER INOCULATION (PLANTS 22 DAYS OLD)				SERIES 2540—PLANTED 30 DAYS AFTER INOCULATION (PLANTS 22 DAYS OLD)			
Uninoculated	5	None	....	None	3	None	....	None
Bacterial infusion	4	None	....	None	2	2	Small	Few
Bacterial infusion + soil (B. S. L.)*	3	2	Small	Few	5	None	....	None
Bacterial infusion + soil (G. S. L.)†	3	None	....	None	5	None	....	None
Bacterial infusion + soil + 10 per cent sugar	4	None	....	None	4	None	....	None
Bacterial infusion + soil + 1 per cent sugar	4	None	....	None	5	None	....	None
Bacterial infusion + soil + 0.1 per cent sugar	3	None	....	None	5	None	....	None
Bacterial infusion + soil + 0.01 per cent sugar	3	None	....	None	4	None	....	None
Bacterial infusion + soil + 1 per cent $CaCO_3$	4	1	Small	3	6	None	....	None
Bacterial infusion + soil + 0.1 per cent $CaCO_3$	5	None	....	None	4	None	....	None
Bacterial infusion + soil + 0.01 per cent $CaCO_3$	5	None	....	None	3	None	....	None
Bacterial infusion + soil + 1 per cent $Ca_3(PO_4)_2$	5	None	....	None	5	None	....	None
Bacterial infusion + soil 0.1 per cent $Ca_3(PO_4)_2$	4	None	....	None	4	None	....	None
Bacterial infusion + soil + 0.01 per cent $Ca_3(PO_4)_2$	4	None	....	None	5	None	....	None
Bacterial infusion + soil + 1 per cent each $Ca_3(PO_4)_2$ + sugar + $CaCO_3$	3	None	....	None	4	1	Small	1
Bacterial infusion + soil (B. S. L.)* + 0.1 per cent $CaCO_3$	5	None	....	None	5	None	....	None

* Brown silt loam.

† Gray silt loam.

Sugar and $Ca_3(PO_4)_2$ used on brown silt loam, and $CaCO_3$ used on gray silt loam.

dissolved in infusion, the nodules produced were larger and more uniform in size. Whether this effect was due to the stimulative action of sugar or to other factors was not determined. Soil alone showed a slight benefit but not so much as sugar.

A comparison of the data reported in tables 8 and 9 reveals no marked difference between smooth and wrinkled peas with respect to nodule production. The relative smoothness of the seed coat may therefore be considered a negligible factor.

Experiment 3—The effect of varying amounts of calcium carbonate, tricalcium phosphate, and sugar in soil on the duration of the life of nodule bacteria in the soil and after being applied to the seed

Two types of soil were used, brown silt loam having a lime requirement of 300 pounds, and gray silt loam on tight clay having a lime requirement of 1300 pounds as determined by the Hopkins' method. The brown silt loam was used with sugar and tricalcium phosphate and also with calcium carbonate. The gray silt loam was used only with calcium carbonate. Pure cultures of garden pea bacteria were tested in this experiment.

One pound of soil was the basis for each preparation. The inoculation was on the basis of 5 cc. of infusion of pea bacteria for each pound of soil. Each mixture was prepared and thoroughly mixed before the infusion was added. The amount for each substance used was on the percentage basis. The soils contained 20 per cent moisture when mixed. After preparation, the various treatments were placed in pint glass jars provided with caps and were stored on the side shelf in the laboratory.

Two grams of the mixture was used to inoculate 1 ounce of sterilized pea seeds and a few cubic centimeters of sterile water was added while inoculating in order to secure thorough distribution of the organisms. The inoculated seeds were placed in glass tumblers and stored in a drawer in the laboratory.

The intervals of planting are shown in table 11.

The data reported in table 12 show that the seeds planted immediately after inoculation as well as those stored 10 days after being inoculated, in all cases, produced numerous nodules. The untreated bacterial infusion showed greater fluctuations in the number of nodules than any of the other treatments. A very striking result was obtained after the seed had been stored 20 days before planting. No nodules were produced from this planting except with the treatment containing the bacterial infusion and brown silt loam, where a few small nodules were found, and also in the treatment containing the bacterial infusion and 1 per cent calcium carbonate, where 3 nodules were found on one plant. This, however, is looked upon as accidental. Storing the inoculated seeds for 30 days before planting resulted in no nodule production in any of the treatments except in the untreated bacterial infusion, which produced a few small nodules, and also in the treatment containing bacterial infusion, soil, and $\frac{1}{10}$ per cent each of tricalcium phosphate, calcium carbonate, and sugar, where 1 nodule was found on one plant.

It is quite apparent from the above statements that the bacteria in the infusion applied to these soils in conjunction with sugar, limestone, and phosphate, died out very rapidly, and were nearly extinct in 20 days. It should be remembered that these mixtures were made with soil, portions of which were

TABLE 13

The effect of varying amounts of calcium carbonate, tricalcium phosphate, and sugar upon the duration of life of nodule bacteria in moist stored soil

TREATMENT	NUMBER OF PLANTS	PLANTS WITH NODULES	NODULE RECORD	
			Size	Number
Series 2560—Soil stored 41 days before inoculating seeds for immediate planting (plants 20 days old)				
Uninoculated	3	None	....	None
Bacterial infusion + soil (B. S. L.)*	5	5	Medium	Many
Bacterial infusion + soil (G. S. L.)†	4	4	Medium	Many
Bacterial infusion + soil + 10 per cent sugar	4	None	....	None
Bacterial infusion + soil + 1 per cent sugar	4	None	....	None
Bacterial infusion + soil + 0.1 per cent sugar	4	4	Medium	Many
Bacterial infusion + soil + 0.01 per cent sugar	4	4	Medium	Many
Bacterial infusion + soil + 1 per cent $CaCO_3$	5	5	Medium	Many
Bacterial infusion + soil + 0.1 per cent $CaCO_3$	2	2	Medium	Few
Bacterial infusion + soil + 0.01 per cent $CaCO_3$	Died	Died	Died	Died
Bacterial infusion + soil + 1 per cent $Ca_3(PO_4)_2$	5	5	Medium	Many
Bacterial infusion + soil + 0.1 per cent $Ca_3(PO_4)_2$	3	3	Medium	Many
Bacterial infusion + soil + 0.01 per cent $Ca_3(PO_4)_2$	4	4	Medium	Many
Bacterial infusion + soil + 0.01 per cent $Ca_3(PO_4)_2$ + sugar + $CaCO_3$	3	3	Medium	Many
Bacterial infusion + soil + 0.1 per cent $CaCO_3$	5	5	Medium	Many
Series 2580—Soil stored 107 days before inoculating seeds for immediate planting (plants 30 days old)				
Uninoculated	5	None	....	None
Bacterial infusion + soil (B. S. L.)*	5	5	Large	Many
Bacterial infusion + soil (G. S. L.)†	5	5	Large	Many
Bacterial infusion + soil + 0.1 per cent sugar	4	4	Large	Many
Bacterial infusion + soil + 0.01 per cent sugar	3	3	Large	Many
Bacterial infusion + soil + 1 per cent $CaCO_3$	5	5	Medium	Many
Bacterial infusion + soil + 0.01 per cent $CaCO_3$	6	6	Medium	Many
Bacterial infusion + soil + 1 per cent $Ca_3(PO_4)_2$	5	5	Medium	Many
Bacterial infusion + soil + 0.01 per cent $Ca_3(PO_4)_2$	5	5	Medium	Few

* Brown silt loam.

† Gray silt loam.

used immediately for inoculating the seed, after which the seed remained in storage for the time stated. The mixtures of soil with limestone, phosphate, and sugar were kept moist and at the end of 41 days and 107 days, respectively, portions of these moist mixtures were applied, as in the first part of this experiment, to sterile seeds, and the seeds were planted immediately.

It may be pointed out that the same mixtures, when used immediately and allowed to dry out in a very short time, would be expected to perform quite differently from when kept moist for a number of months before being applied to the seed. In the first case, there would be little opportunity for the limestone to correct acid soil conditions and for the sugar to supply a source of energy, whereas in the second case, ample opportunity exists for these changes. The contact of the organisms with the acid soil in the first case was greater than the contact with the corrective materials. Because of the above conditions, it was anticipated that entirely different results would be obtained in the two cases.

The results presented in table 13 indicate that soils stored moist for 41 days with the above named treatments, produced infection on peas in all cases except 3, namely, the uninoculated soils and those receiving respectively 10 per cent and $\frac{1}{10}$ per cent sugar. When the period of storage was 107 days, nodules were produced in all cases except with the uninoculated checks.

Experiment 4—The effect of different containers for storing inoculated seed upon the life of legume organisms

The seeds used for this experiment were inoculated seeds with the same treatments as in experiment 1. The inoculated and treated seeds of each of the different legumes were mixed thoroughly and divided into two portions. One portion of 2 quarts was stored in a 2-quart Mason glass jar, and the other portion containing 10 quarts was stored in a seed bag. The jars were stored in the laboratory locker, and the bags in the laboratory store room. Humidity and temperature conditions were approximately the same in both places.

After 5-months storage, the variously treated seeds were planted in pint jars of sterilized quartz sand. Seven seeds were planted in each jar and 5 jars were used for each lot of seeds. All the plants were allowed to grow for 30 days in order to insure the maximum nodule production.

All plants grew normally up to 20 days, but from that time on, the plants from seeds stored in glass jars became yellow and stopped growing, whereas the plants from seeds stored in bags were green and continued to grow. Examination showed that nodules were absent on the roots of all the plants from seeds stored in glass containers, whereas the plants from seeds stored in bags developed several nodules. The results were the same for the three legumes used, soybeans, sweet clover, and garden peas.

PART II.—THE ENDURANCE OF NODULE BACTERIA IN THE PRESENCE OF OTHER ORGANISMS, AND IN THE PRESENCE OF EACH OTHER

Experiment 5—The endurance of pea bacteria in the presence of B. radiobacter

One cubic centimeter each of pea bacteria infusion and *B. radiobacter* infusion was transferred into each of 2 bottles of mannite agar media and 2

bottles of cane sugar media. After incubation at 26°C. for 10, 20, and 30 days, portions were tested on potato, in milk, and for inoculation of peas.

Test on milk. One loopful of infusion from each bottle was transferred into a test tube of sterile milk. The tubes were incubated at 26°C. and examinations were made at different periods.

Test on potato slant. One loopful of infusion from each bottle was transferred to potato slant prepared in test tubes. These tubes were incubated at 26°C. and examinations were made.

Test on inoculation. One cubic centimeter of infusion from each bottle was used to inoculate ½ ounce of sterilized pea seeds. Five inoculated pea seeds were immediately planted in jars from each 1½-ounce lot of seed. Four replicates from each lot were thus planted.

Experiment 6—The endurance of cowpeas, soybean, and sweet clover organisms in the presence of B. radiobacter

Three separate mixtures were prepared of *B. radiobacter*, with cowpea, soybean, and sweet clover bacteria respectively, 1-cc. portions of the respective infusions being used in each case. These were incubated, as in experiment 5, on both mannite and cane sugar agar at 26°C. and tested at 10-, 20-, and 30-day intervals in milk, on potato slants, and for ability to produce nodules.

Experiment 7—The endurance of pea, cowpea, soybean and sweet clover bacteria in the presence of Azotobacter chroococcum

Garden pea, cowpea, soybean, and sweet clover bacteria were grown in the presence of *Azotobacter chroococcum* as in experiment 6 except that only mannite agar was used, and the tests on potato slant were omitted.

Experiment 8—The endurance of pea bacteria in the presence of B. prodigiosus, B. capsulatus, B. subtilis, B. mesentericus, pink yeast, and molds

A loopful of an infusion of pea bacteria was mixed with a loopful of an infusion of each of *B. prodigiosus*, *B. capsulatus*, *B. subtilis*, *B. mesentericus*, *pink yeast*, and *molds* in separate tubes of sterile milk. The tubes were incubated for 14 days at 26°C., and after the results of the growth in milk were recorded, tests for inoculation were conducted. This experiment was carried out in duplicate tubes.

In all the bottles where the legume organisms of different kinds were grown with *B. radiobacter*, the growth appearing on the agar was typical of *B. radiobacter*. This was due to the fact that *B. radiobacter* grew faster than any legume organisms used. It would seem that the legume organisms would soon perish, either for lack of food or oxygen. Although they might have been deprived of food and oxygen, their viability was very little, or not at all, affected as measured by nodule production. The legume organisms may have changed

TABLE

The growth of cowpea, soybean, and sweet clover organisms with B. radiobacter on mannite agar media

Test on potato

NUMBER OF TUBES	ORGANISMS	INCUBATION PERIOD ON MANNITE AGAR	DESCRIPTION OF GROWTH ON POTATO AFTER SIX DAYS
		days	
9	Uninoculated		Potato unchanged
4	Cowpea bacteria + *B. radiobacter*	10	Potato turned gray
4	Cowpea bacteria + *B. radiobacter*	20	Potato turned gray
4	Cowpea bacteria + *B. radiobacter*	30	Potato turned gray
4	Soybean bacteria + *B. radiobacter*	10	Potato turned gray
4	Soybean bacteria + *B. radiobacter*	20	Potato turned gray
4	Soybean bacteria + *B. radiobacter*	30	Potato turned gray
4	Sweet clover bacteria + *B. radiobacter*	10	Potato turned gray
4	Sweet clover bacteria + *B. radiobacter*	20	Potato turned gray
4	Sweet clover bacteria + *B. radiobacter*	30	Potato turned gray

NUMBER OF TUBES	ORGANISMS	INCUBATION PERIOD ON MANNITE AGAR	DESCRIPTION AFTER	
			4 days	14 days
		days		
9	Uninoculated		Milk unchanged	Milk unchanged
4	Cowpea bacteria + *B. radiobacter*	10	Clear serum on top	Milk turned brown
4	Cowpea bacteria + *B. radiobacter*	20	Clear serum on top	Milk turned brown
4	Cowpea bacteria + *B. radiobacter*	30	Clear serum on top	Milk turned brown
4	Soybean bacteria + *B. radiobacter*	10	Clear serum on top	Milk turned brown
4	Soybean bacteria + *B. radiobacter*	20	Clear serum on top	Milk turned brown
4	Soybean bacteria + *B. radiobacter*	30	Clear serum on top	Milk turned brown
4	Sweet clover bacteria + *B. radiobacter*	10	Clear serum on top	Milk turned brown
4	Sweet clover bacteria + *B. radiobacter*	20	Clear serum on top	Milk turned brown
4	Sweet clover bacteria + *B. radiobacter*	30	Clear serum on top	Milk turned brown

Test for inoculation (plants 30 days old)

NUMBER OF JARS	ORGANISMS	INCUBATION PERIOD ON MANNITE AGAR	NUMBER OF PLANTS	PLANTS WITH NODULES
		days		
18	Uninoculated		71	None
4	Cowpea bacteria + *B. radiobacter*	10	14	14
4	Cowpea bacteria + *B. radiobacter*	20	16	16
4	Cowpea bacteria + *B. radiobacter*	30	16	16
4	Soybean bacteria + *B. radiobacter*	10	11	11
4	Soybean bacteria + *B. radobacter*	20	14	14
4	Soybean bacteria + *B. radiobacter*	30	14	14
4	Sweet clover bacteria + *B. radiobacter*	10	22	22
4	Sweet clover bacteria + *B. radiobacter*	20	20	20
4	Sweet clover bacteria + *B. radiobacter*	30	13	13

TABLE 15

The growth of pea, cowpea, soybean, and sweet clover bacteria with Azotobacter chroococcum on mannite agar media

Test in milk

NUMBER OF TUBES	ORGANISMS	INCUBATION PERIOD ON MANNITE	DESCRIPTION AFTER	
			8 days	13 days
		days		
6	Uninoculated		Milk unchanged	Milk unchanged
2	Pea bacteria + Azotobacter	10	Clear serum on top	Milk turned watery (pea)
2	Pea bacteria + Azotobacter	20	Clear serum on top	Milk turned watery (pea)
2	Pea bacteria + Azotobacter	30	Clear serum on top	Milk turned watery (pea)
2	Cowpea bacteria + Azotobacter	10	Clear serum on top	Brown precipitate (Azotobacter)
2	Cowpea bacteria + Azotobacter	20	Clear serum on top	Brown precipitate (Azotobacter)
2	Cowpea bacteria + Azotobacter	30	Clear serum on top	Brown precipitate (Azotobacter)
2	Soybean bacteria + Azotobacter	10	Clear serum on top	Brown precipitate (Azotobacter)
2	Soybean bacteria + Azotobacter	20	Clear serum on top	Brown precipitate (Azotobacter)
2	Soybean bacteria + Azotobacter	30	Clear serum on top	Brown precipitate (Azotobacter)
2	Sweet clover bacteria + Azotobacter	10	Clear serum on top	Milk turned watery (sweet clover)
2	Sweet clover bacteria + Azotobacter	20	Clear serum on top	Milk turned watery (sweet clover)

Test for inoculation (plants 22 days old)

NUMBER OF JARS	ORGANISMS	INCUBATION PERIOD ON MANNITE	NUMBER OF PLANTS	PLANTS WITH NODULES
		days		
6	Uninoculated		25	None
2	Pea bacteria + Azotobacter	10	7	7
2	Pea bacteria + Azotobacter	20	8	8
2	Pea bacteria + Azotobacter	30	8	8
2	Cowpea bacteria + Azotobacter	10	8	8
2	Cowpea bacteria + Azotobacter	20	10	10
2	Cowpea bacteria + Azotobacter	30	7	7
2	Soybean bacteria + Azotobacter	10	11	11
2	Soybean bacteria + Azotobacter	20	7	7
2	Soybean bacteria + Azotobacter	30	7	7
2	Sweet clover bacteria + Azotobacter	10	7	7
2	Sweet clover bacteria + Azotobacter	20	7	7
2	Sweet clover bacteria + Azotobacter	30	8	8

their stage of existence, or may have been living as well as *B. radiobacter*. There may be a mutual relationship between the legume organisms and *B. radiobacter* but this has not been determined. Löhnis and Hansen (9) stated, "*Bacillus radiobacter* seems to be regularly present in root nodules of leguminous plants, stimulating development and activity." They also reported that *B. radiobacter* and *B. radicicola* are closely related to each other as shown in the morphology of the cell.

Whiting has further studied the question of the beneficial influence of *B. radiobacter* on cowpeas, soybeans, and other legumes, but has not found tangible evidence that *B. radiobacter* is desirable. On the contrary, he has found this organism destructive to nodule production in certain mixed cultures.

The fact that tests on potato and in milk showed the presence of *B. radiobacter*, does not necessarily mean that the legume organisms were dead or absent.

In the case where *Azotobacter chroococcum* was used instead of *B. radiobacter*, the infective power of different legume organisms used was not hindered, as is shown by inoculation test.

The survival of legume organisms in the presence of certain contaminating organisms of course depends upon many factors, particularly when grown on artificial media. The time factor is one very important consideration. In these experiments, transferring did not enter in, and this, of course, might greatly alter the results.

SUMMARY

In experiment 1 where inoculated seeds were variously treated with soil, glue, and sugar, applied alone and in combination, some legume organisms remained variable and nodule production occurred after 60-days storage in small seed bags under ordinary conditions.

In the treatments where sugar was used, applied either alone or with glue or soil, the nodules developed were uniformly large, and evenly distributed over the root system. Soil and glue did not show any particular advantages over the untreated bacterial infusion.

The irregularity in nodule production as shown in experiment 1 at different times of planting was thought to be due to the mechanical effect of mixing at the time of inoculation. The most pronounced irregularity occurred with sweet clover, probably because of the small size of the seed with consequent greater surface to cover.

The results of experiment 2 showed that the sugar treatment, either dissolved in bacterial infusion and then applied to the seeds, or applied on inoculated seeds, gave better results in nodule production than soil prepared in the same manner. The use of soil with sugar gave no better results than sugar alone.

No difference in nodule production was noticed between treatments dissolved in bacterial infusion previous to its application on sterile seeds and treatments applied directly on inoculated seeds before mixing.

No significant difference in nodule production was noticed between sugar, tricalcium phosphate, and calcium carbonate in different amounts with infected soil when used for inoculation.

Soils containing 10 per cent sugar developed acidity which was entirely unfavorable to the life of *B. radicicola*. This organism remained alive in moist soils after 107-days storage in pint glass jars with various treatments.

Cloth seed bags for storing inoculated seeds are far superior to glass containers for maintaining the life of the legume organisms.

B. radiobacter and *Azotobacter chroococcum* showed no harmful effects upon the life and infecting power of the nodule bacteria under the conditions established and during the time tested.

Soybean, sweet clover, cowpea, and garden pea bacteria, when grown together, showed no harmful effect upon each other.

The activity of pea bacteria when grown in milk was not impaired by the presence of any one of the organisms tested; namely, *B. prodigiosus*, *B. capsulatus*, *B. subtilis*, *B. mesentericus*, *pink yeast*, and *molds*.

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A NEW SOIL CORE SAMPLER

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The proper sampling of a soil is no simple undertaking. Both care and experience are required for best results. For many purposes, the old methods of securing representative samples with the auger or spade are satisfactory because the physical disturbance to which the soil is subjected does not alter its chemical composition. When the detailed physical properties of the natural soil are to be studied, however, a modified method of sampling is needed.

Certain colloid investigations at the Missouri Experiment Station made desirable some very careful studies on the rates of percolation of water through a heavy subsoil when treated with various salts. It was, therefore, imperative that the structure of the soil should remain undisturbed, In order to accomplish this it was necessary to develop a sampler that would take an undisturbed core of soil with the desired dimensions. This necessity encouraged the development of the sampler described in this paper.[1]

The accompanying detailed drawing shows the plan of the sampler, which consists essentially of two cyclinders, one within the other, the outer one being furnished with cutting knives. *A* is the top view of the outer cylinder showing steel head and three brass rollers. This cylinder head has a threaded hole $2\frac{7}{8}$ inches in diameter for the insertion of handle *H*. These three brass rollers spaced at equal distances around the cylinder are 1 inch in diameter and $\frac{3}{16}$ inch thick. They roll on rim *D* which fits on cylinder *F* when in operation. These rollers are secured to the wall of cylinder *C*. *B* is a side view of the same cylinder head, showing raised center for the support of handle *H*. This cut also shows a groove for the rollers, which have already been mentioned. The cylinder head *B* fits into cylinder *C* where it is secured by four screws, two of which are shown in the drawing.

Cylinder *C* is heated so it will go over the lower portion of head *B* and shrink

[1] In Bulletin 94 of the Iowa Agricultural Experiment Station, W. H. Stevenson describes a sampler devised and used at that station. It is to this piece of work that the writer is indebted for many valuable suggestions used in the development of this sampler. Acknowledgment is made to Dr. R. Bradfield and to Dr. W. A. Albrecht of this station for their assistance in the development of this sampler. Much credit also must be given to Mr. Gus. Tornsjo, chief mechanician of the university, to whose skill the working out of the mechanical details was largely due.

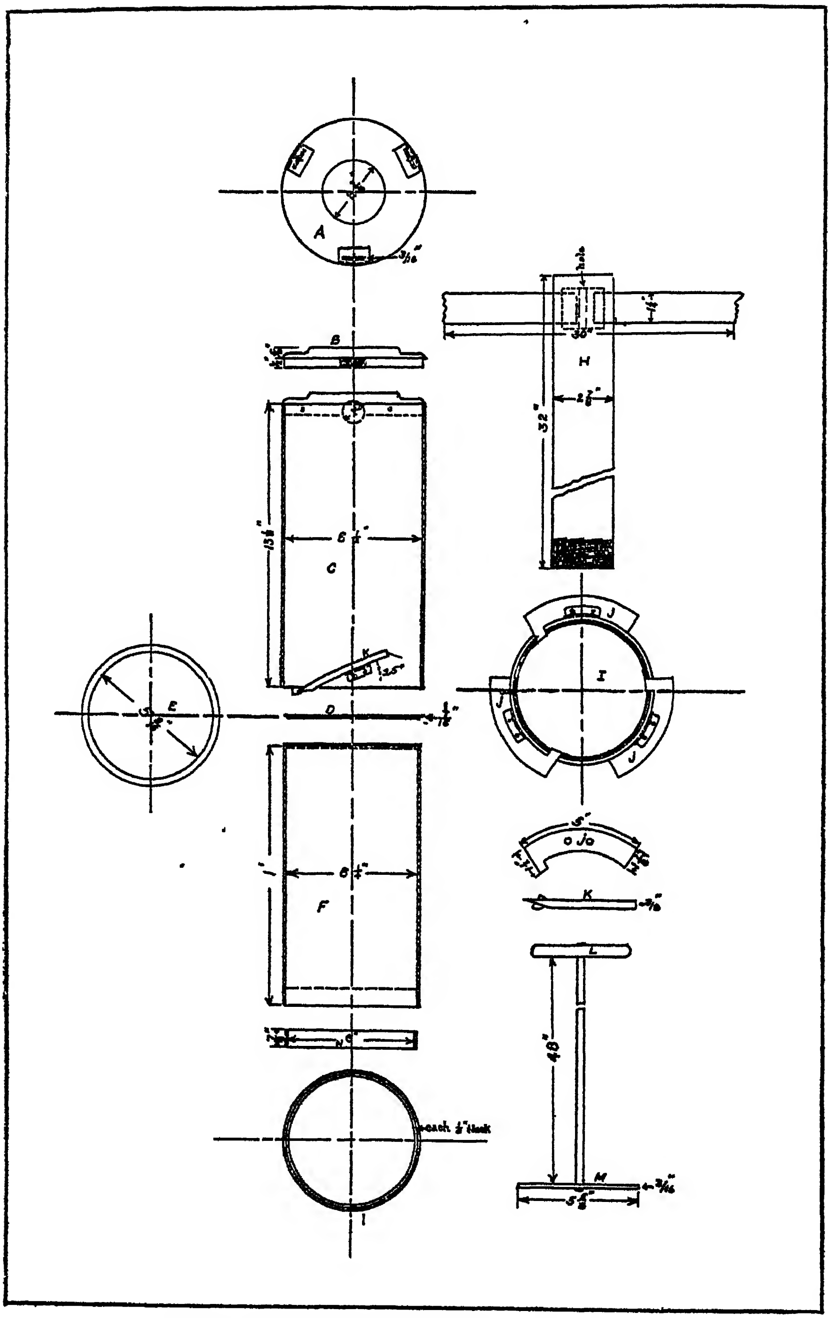

FIG. 1. PLAN OF THE NEW SOIL CORE SAMPLER

tightly in place. This prevents the cylinder from becoming distorted when force is applied to rotate the sampler in hard soil. Cylinder C is brass, the wall is $\frac{1}{8}$ inch thick and $13\frac{1}{8}$ inches long. The inside diameter is $6\frac{1}{2}$ inches. The knives, one of which is shown as K, are fastened to the outer wall of this cylinder at an angle of 25° as shown in the drawing, and are removable. The rim D is steel; it is $\frac{7}{16}$ inch thick and $\frac{15}{16}$ inch wide. This rim has a shoulder which fits on top of cylinder F; the lower portion extending into the top of the cylinder as shown. This rim is removable and furnishes a track upon which the rollers in cylinder C operate. E is the top view of rim D. Cylinder F is also made of brass, and has a wall $\frac{1}{8}$ inch thick. It fits just inside cylinder C. Both cylinders are bored true. At the lower end of cylinder F there is a stationary band N, $\frac{7}{8}$ inch wide and $\frac{1}{8}$ inch thick. This band is made of brass and is not removable. G is an end view of cylinder F with the included band. H is the handle complete. These parts are made from gas pipes with dimensions as given on the drawing. The threaded end of this handle screws into the cylinder head A. The cross handles are connected in the center as indicated. The plunder rod extends through this hole.

I is an end view of the sampler showing the knives, J, in place. The innertips of these knives are bronze, are soldered on the steel knives, and extend just inside of the inner rim of the band N. J shows a knife as it appears from the bottom view when detached. K is the same knive showing the edge view. Plunger M has a steel disc $5\frac{5}{8}$ inches in diameter. It fits in cylinder F with the handle projecting through handle H of the sampler. The plunger handle L is removable. It has a square hole through the center which fits the square end of the plunger rod. This plunger rod is used to push cylinder F out of cylinder C, then it is inserted into the lower end of cylinder F to remove the core of soil.

When taking a core of soil with this sampler, all grass and trash must be removed from the surface of the soil, for if such material is not removed it will hang on the knives and as a result, the upper part of the core will be disturbed.

Considerable care is required to start the sampler, as it may slip about before taking hold. To prevent this, a frame may be built to hold it steady. Such a frame is shown in the accompanying cut. No definite type of frame is needed, but the sampler must be held steady. The frame holds the sampler true while it is being operated so that the core will not be broken or disturbed. The rotation of the sampler causes the knives to cut away a strip of soil $1\frac{1}{2}$ inches wide. This rotation is continued until the desired depth is reached—up to 12 inches—after which the core is broken off below the cylinder by pulling the handle to one side.

The sampler is then removed from the soil, placed against the frame as shown in plate 1, figure 1, and the knives are taken off. The inner cylinder is taken out, rim D removed and the plunger is inserted in the other end of cylinder F to push out the sample. The core of soil continues to rest on the plunger until it is carefully wrapped with screen wire. (Plate 1, Fig. 2.) The wrapped core

is then made air-tight by dipping it in a can of hot paraffine. It is allowed to cool and is redipped until the desired thickness of paraffine is secured. This is best done in the field.

This sampler has been used with satisfaction on both surface soils and subsoils. Better results are secured when the soil is moist than when it is either too dry or too wet. The best moisture conditions are about the same as for plowing. Good samples have been taken from silt loams, from sandy loams, and from clays. A sandy soil requires special care. Soils containing gravel, rock, or an abundance of coarse undecomposed organic matter cannot be sampled with satisfaction.

When taking samples of subsoil it is necessary to remove the surface soil from a place large enough to let the frame rest on the subsoil at the depth at which it is wished to start the sample.[2]

[2] Any one especially interested, can make arrangements with the Agricultural Experiment Station, Columbia, Mo., to secure blue prints and specifications for this sampler.

PLATE 1

FIG. 1. Sampler after removal from soil.
FIG. 2. Wrapped core of soil made air-tight with paraffine.

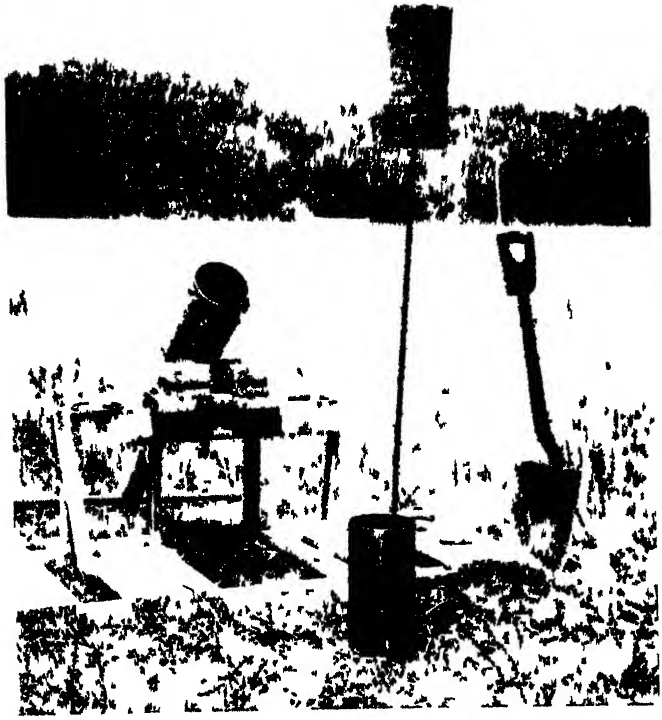

FIG 1

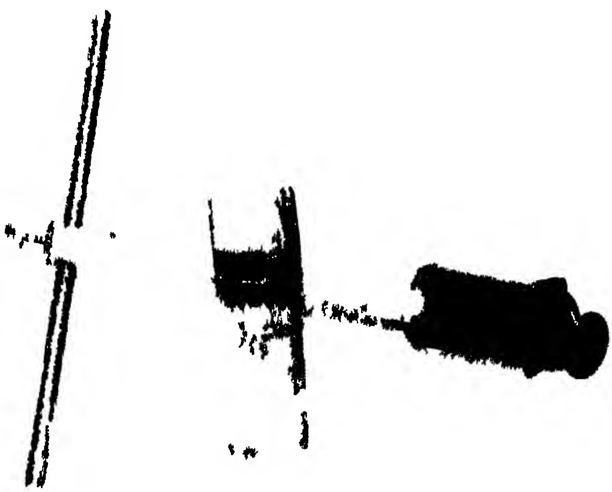

FIG 2

THE AVAILABILITY OF NITROGEN IN GARBAGE TANKAGE AND IN UREA IN COMPARISON WITH STANDARD MATERIALS[1]

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INTRODUCTION

The principal objects in the work reported in this paper are: First, to study the relative availability of garbage tankage in comparison with other organic and inorganic nitrogenous fertilizers; and second, to study the rate of decomposition of urea under various conditions, as well as to find out its relative availability.

The subject of garbage disposal has been and is still a matter of considerable importance, not only from the health point of view, but also from the economic standpoint. Garbage rendering plants have been in operation for the purpose of recovering from garbage, certain products such as fats, but no particular use has been found for the residue. Turrentine (10) points out that in the United States during 1914 the production of garbage tankage roughly estimated was 150,000 tons, valued at $975,000. This was obtained from 1,200,000 tons of raw garbage rendered in about 25 plants. The garbage collected in 1909 in cities having a population of 30,000 or over, amounted to 2,700,000 tons, which would be capable of yielding 400,000 tons of dry tankage worth $2,500,000.

Considerable work has been done in the past on the fertilizing value of garbage tankage, but most of the results seem to indicate that its nitrogen availability is low. Lipman and Burgess (4) found that garbage tankage gave results which place it in the same class with steamed bone meal, cottonseed meal, sludge from septic tanks, and goat manure.

Pember and Hartwell (6) showed that plants made no larger growth with garbage tankage as a source of nitrogen, than those to which no nitrogen was added. In chemical tests on the availability of garbage tankage they found that the alkaline permanganate method agreed more closely with vegetation tests than the neutral permanganate method. Further tests at the Rhode Island station (2) in the form of pot experiments showed that insoluble nitrogen in certain brands of fertilizers was practically useless and that the nitrogen of garbage tankage was of low grade.

Schroeder (9) also points out that from chemical tests made, it seemed that

[1] Paper No. 253 of the Journal Series, New Jersey Agricultural Experiment Stations, Department of Soil Chemistry and Bacteriology.

[2] The authors wish to express their indebtedness to Prof. A. W. Blair for suggesting the problem, and for helpful criticism of the work.

the proper use of garbage tankage should give the usual results obtainable from medium or low grade fertilizers. In another paper, Schroeder (8) reports results of pot culture tests compared with those obtained by the alkaline permanganate method. He concludes that a higher availability should be accorded the nitrogen in garbage tankage than would be indicated by the alkaline permanganate method.

1. VEGETATION TESTS

Pots of 2-gallon capacity containing 20 pounds of dry sand were used in this experiment. The general treatment of all the pots was as follows: 4 gm. of acid phosphate, 2 gm. of muriate of potash, 5 gm. of pulverized limestone, 0.5 gm. magnesium sulfate, and 0.2 gm. of ferric sulfate. The moisture content was kept at about 10 per cent. The source of nitrogen was the only varying or limiting factor. The different nitrogen treatments were as follows: (*a*) no nitrogen, (*b*) garbage tankage, (*c*) garbage tankage finely ground (*d*) sodium nitrate, (*e*) ammonium sulfate, (*f*) urea, (*g*) commercial synthetic urea,

TABLE 1

*Yield of dry matter in the crops**

POT TREATMENT	BARLEY	RAPE	SORGHUM
	gm.	*gm*	*gm.*
No nitrogen (check)	3.8	0.93	2.6
Garbage Tankage	6.7	2.00	10.0
Garbage Tankage finely ground	6.7	1.90	6.0
Nitrate of soda	36.5	17.70	26.8
Sulfate of ammonia	32.3	11.70	28.4
Urea (C.P.)	33.3	13.80	31.8
Commercial synthetic urea	34.6	13.50	30.6
Standard tankage	21.3	7.90	21.5
Fish	19.1	7.60	20.4

* Average of 3 pots.

(*h*) standard tankage, (*i*) fish. All forms of nitrogen were applied at a rate equivalent to 2 gm. of nitrate of soda which actually contained 0.315 gm. of nitrogen. The garbage tankage analyzed 3.13 per cent total nitrogen. There were three pots for each nitrogenous material used. Two series of pots were prepared at the same time. Barley was planted in one series of pots and rape in the other. At a later date, another series of pots was prepared as above and sorghum was grown. The barley and rape were planted in the middle of February, and harvested the first part of May. The sorghum experiment was started May 4 and harvested July 6.

Yields of dry matter

The yields of dry matter for the different nitrogenous treatments with the three different crops are shown in table 1. With the barley crop, nitrate of

soda gave the largest yield, 36.5 gm., and garbage tankage the lowest, 6.7 gm. However, the yield in the garbage tankage treated pots was double that of the check, or no nitrogen pots. The two forms of urea yielded 33.3 and 34.6 gm. of dry matter, closely approaching the yield with nitrate of soda; and the sulfate of ammonia ran a close third with 32.3 gm. The same order holds true with the rape crop, and the standard tankage and fish gave yields about half as great as those from the sodium nitrate, with the preference for the standard tankage. With the sorghum plants, both forms of urea yielded 31 gm.; ammonium sulfate, 28.4 gm.; and nitrate of soda, 26.8 gm. It is also interesting to note that the garbage tankage, in this case, yielded three to four times as much as the no nitrogen pots. Pinckney (7) has pointed out that sorghum plants are good indicators of available nitrogen, and the appearance of these plants during their growing period seemed to bear out this fact. Attention may be called to the fact that the finely ground garbage tankage

TABLE 2

*Percentage of nitrogen in the crops**

POT TREATMENT	BARLEY	RAPE	SORGHUM
	per cent	*per cent*	*per cent*
Nitrogen (check)	0.774	1.140	0.656
Garbage tankage	0.901	1.388	0.599
Garbage tankage finely ground	0.825	1.529	0.698
Nitrate of soda	0.732	1.080	0 670
Sulfate of ammonia	0.788	1.422	0.543
Urea (C.P.)	0.839	1.346	0.535
Commercial synthetic urea	0.760	1.331	0.591
Standard tankage	0.718	1.248	0.529
Fish	0.802	1.140	0.492

* Average of 3 pots.

produced a considerably smaller crop of sorghum than the more coarsely ground garbage tankage.

Percentage of nitrogen in the crops

The percentages of nitrogen in the dry matter of the various crops are shown in table 2. The differences are not especially significant. The percentage of nitrogen in garbage tankage tends to run the highest in all of the crops, but this frequently happens when the crop yield is low, because of unavailable nitrogen. On the other hand, where there is a large yield of dry matter, as is the case with sodium nitrate, the percentage of nitrogen in the crop may be somewhat lower. This, however, does not hold true in the case of urea. Here the percentage of nitrogen is high with a high yield of dry matter, which would indicate that the nitrogen in urea is very readily available to plants.

Percentage of nitrogen recovered in the crops

The percentage of nitrogen recovered in the crops is shown in table 3. With the barley crop, it is interesting to note that the urea (C.P.) gave the highest percentage of nitrogen recovered, 77.37 per cent as against 75.49 per cent for nitrate of soda, even though the yield of dry matter was greater with the latter. The percentages of nitrogen recovered with commercial urea and nitrate of soda are about the same, the amount in each case being slightly more than the

TABLE 3

*Percentage of nitrogen recovered in the crops**

POT TREATMENT	BARLEY	RAPE	SORGHUM
	per cent	*per cent*	*per cent*
No nitrogen (check)	.....	.....	.....
Garbage tankage	9.84	5.46	13.60
Garbage tankage finely ground	8.22	5.87	7.87
Nitrate of soda	75.49	57.33	51.60
Sulfate of ammonia	71.14	49.46	43.52
Urea (C.P.)	79.37	55.59	48.57
Commercial synthetic urea	74.16	53.68	52.00
Standard tankage	39.26	27.93	30.66
Fish	39.31	24.13	27.60

* Average of 3 pots.

TABLE 4

Relative availability

Using 100 for nitrate of soda as a basis

POT TREATMENT	BARLEY	RAPE	SORGHUM	AVERAGE
	per cent	*per cent*	*per cent*	*per cent*
No nitrogen	.....	.....	.....	.....
Garbage tankage	13.0	9.5	26.4	16.3
Garbage tankage (finely ground)	10.9	10.2	15.3	12.1
Nitrate of soda	100.0	100.0	100.0	100.0
Sulfate of ammonia	94.2	86.2	84.3	88.2
Urea (C.P.)	105.1	96.9	94.1	98.7
Commercial synthetic urea	98.2	93.6	100.7	97.5
Standard tankage	52.0	48.7	59.4	53.4
Fish	52.1	42.1	53.5	49.2

recovery with ammonium sulfate. Standard tankage and fish gave almost identical results as to amount of nitrogen recovered—39.26 per cent and 39.31 per cent respectively. The garbage tankage averaged about 9 per cent nitrogen recovered.

With the rape crop, nitrate of soda again resumed first place in amount of nitrogen recovered, with urea (C.P.) a close second, the amounts being 57.35 and 55.6 per cent respectively.

Commercial urea and nitrate of soda used with the sorghum gave almost

identical results. The other nitrogenous materials follow in the same order as under barley.

Table 4 expresses the relative availability of the various nitrogenous materials on the basis of 100 for nitrate of soda. In the last column, which shows the average of the three crops, urea (C.P.) is close to the nitrate of soda with 98.7 per cent available. Commercial synthetic urea rates 97.5 per cent, and sulfate of ammonia falls to 88.2 per cent. On this basis, the garbage tankage averages about 14 per cent; standard tankage, 53.4 per cent; and fish, 49.2 per cent.

Conclusions

It is evident from the foregoing data that the fertilizing value of garbage tankage is very low. Most of the nitrogen which it contains is slowly available, and the total amount of nitrogen which it contains is very low in comparison with other forms of organic nitrogen. As a fertilizing material, its chief value seems to be as a filler.

Urea was found to be a very desirable source of nitrogen and was very nearly equal to nitrate of soda in availability. In some cases the crop yield was even greater than with nitrate of soda. In all cases, it was better than with sulfate of ammonia.

2. CHEMICAL TESTS

Chemical tests for the availability of organic nitrogen have always been more or less failures. Of the two methods outlined in the Official Methods of Analysis (1), both usually give results which differ widely from the vegetation tests. The neutral permanganate method especially has been found by most workers to give values much too high. The alkaline permanganate method gives results that more nearly approach the vegetation tests, but the values obtained are also usually too high. A new method "Oxalic Acid" by Kellogg (3) has recently been tried out, and although far from perfect, gives results which are more in accord with actual vegetation experiments.

These three methods were tried out on the garbage tankage, on the standard tankage, and on the fish used in the above vegetation experiments. The results are given in tables 5, 6, and 7. The only values obtained which approximate those obtained in the vegetation tests are those secured by the Kellogg Oxalic Acid method. Even by this method the value for the standard tankage is much too low. By all three methods fish shows a higher availability than the standard tankage, but vegetation tests show the opposite to be true.

From the results of this work it would appear that the present chemical methods for determining available organic nitrogen are not satisfactory.

Decomposition of urea

The results of the vegetation tests reported above, indicate that urea is a very readily available source of nitrogen. The decomposition of the urea was

apparently very rapid even in sand cultures, for the plants showed no lack of nitrogen from the start. The authors decided to determine at what rates the urea was decomposed with different percentages of soil and sand. The recent work of Littauer (5) should be mentioned in this connection. He showed that the rapidity of urea decomposition was dependent on the kind of soil, soil

TABLE 5

Neutral permanganate method

MATERIAL	WATER-SOLUBLE	WATER-INSOLUBLE ORGANIC NITROGEN SOLUBLE IN NEUTRAL PERMANGANATE		WATER-INSOLUBLE ORGANIC NITROGEN INSOLUBLE IN NEUTRAL PERMANGANATE	TOTAL NITROGEN	PROPORTION OF TOTAL NITROGEN AVAILABLE
	per cent	*per cent*	*per cent of total*	*per cent*	*per cent*	*per cent*
Garbage tankage.........	0.40	1.88	60.0	0.85	3.13	72.8
Ordinary tankage........	1.18	6.80	76.7	0.89	8.87	89.9
Fish..................	2.65	5.28	64.3	0.29	8.22	96.5

TABLE 6

Alkaline permanganate method

MATERIALS	WATER SOLUBLE	ACTIVE WATER INSOLUBLE ORGANIC NITROGEN		INACTIVE WATER INSOLUBLE ORGANIC NITROGEN	TOTAL NITROGEN	PROPORTION OF TOTAL NITROGEN AVAILABLE
	per cent	*per cent*	*per cent of total*	*per cent*	*per cent*	*per cent*
Garbage tankage.........	0.40	0.92	29.4	1.81	3.13	42.2
Ordinary tankage........	1.18	4.77	53.8	2.92	8.87	67.1
Fish..................	2.65	3.53	43.0	2.04	8.22	75.2

TABLE 7

Kellogg's oxalic acid method

MATERIALS	WATER-SOLUBLE	WATER-SOLUBLE PLUS THAT SOLUBLE IN 0.01 N OXALIC ACID	INSOLUBLE IN WATER AND 0.01 N OXALIC ACID	TOTAL NITROGEN	PROPORTION OF TOTAL NITROGEN AVAILABLE
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Garbage tankage..................	0.40	0.65	2.48	3.13	20.8
Ordinary tankage..................	1.18	1.95	6.92	8.87	22.0
Fish............................	2.65	3.08	5.14	8.22	37.5

moisture, and temperature. In a loam soil the decomposition of urea was completed in 10 days at 20°, whereas it took 28 days at 0°. In sand cultures 65 per cent of the urea was decomposed in 10 days at 20°, and 20 per cent in 28 days at 0°. Littauer also states that drying limits urea decomposition in the same way as sandy soil. Furthermore, the decomposition of urea goes on more

rapidly in a soil rich in bacteria where there is sufficient moisture. In order to hasten the decomposition of urea and to prevent loss of ammonia, Littauer found it was necessary to mix the urea well with the soil, and not to expose it on the surface. Another interesting point brought out was that unlike nitrates, there is no danger of leaching, because ammonium salts are absorbed and held near the surface of the soil.

Experimental

In the experiments tried out on the rate of decomposition of urea with different percentages of soil and sand, tumblers containing 100 gm. of the dry soil or sand mixtures were used. About 10 per cent moisture was used in the sand tumblers, and about 15 per cent in the soil and half sand. An aliquot, equivalent to 0.1 gm. urea solution, was added to each tumbler and thoroughly mixed. This amount of urea contains 0.0462 gm. nitrogen. The cultures were maintained at room temperature. After standing different periods of time, the contents of each tumbler were transferred to a flat bottom 1-liter flask, and 500 cc. of a 10 per cent potassium chloride solution was added. This was shaken in a mechanical shaker for ½ hour, and then filtered. Nitrogen was determined in the usual way by distilling 250 cc. of the filtered solution into standard acid. Since on distillation a small amount of ammonia is given off from a solution of urea, it was necessary to run a blank in all cases. Under some conditions, this amounted to 2 mgm. of nitrogen and under others to 3 mgm.

Discussion

The percentages of nitrogen converted to ammonia in sand, in half sand, and in soil cultures for each day are given in table 8. It is understood in all this work that part of the nitrogen from the urea had been converted to nitrates before the determinations for ammonia could be made, but this represents only a small part of the whole. The object of this work is to measure the rate of decomposition of urea by ammonification tests. Thus, in one experiment (table 8) after 5 days, only 3 per cent was converted to ammonia in the sand cultures, 67.1 per cent in the half sand culture, and 89.2 per cent in the straight soil culture.

When the experiment was repeated and carried through to 8 days, 6.9 per cent of the urea was converted to ammonia in the sand, 87.0 per cent in the half sand, and 92.2 per cent in the straight soil. With the soil alone, over 50 per cent was converted to ammonia within 3 days. In all of these experiments, 0.1 gm. of urea was used per 100 gm. of soil. With this or smaller amounts of urea, the soil was capable of absorbing and holding the ammonia produced but with larger amounts the soil could not absorb all the ammonia produced; therefore much was lost.

A further experiment was conducted to determine the rate of decomposition of urea in a very acid soil, and also in an acid soil to which varying amounts of pulverized limestone had been added. The soil chosen for this purpose was

one which had received a rather heavy application of ammonium sulfate for about 15 years but which had not been limed, and which had a pH value of about 4.8 at the time of the experiment.

Table 9 shows the results of the decomposition of the urea through a period of 11 days and under the conditions of no lime and of lime. Three different

TABLE 8

Rate of decomposition of urea

In per cent nitrogen converted to ammonia

PERIOD OF TIME		SAND	HALF SAND HALF SOIL	SOIL
1 day	1	...	9.5	21.2
	2	1.3	10.8	20.8
2 days	1	3.0	24.3	46.0
	2	1.3	23.8	39.0
3 days	1	2.6	43.7	67.1
	2	1.8	36.0	60.0
4 days	1	2.2	52.4	84.0
	2	2.6	47.2	79.0
5 days		3.0	67.1	89.2
7 days		5.2	87.9	92.2
8 days		6.9	87.0	92.2

TABLE 9

Rate of decomposition of urea in an acid soil

In per cent nitrogen converted to ammonia

PERIOD OF TIME	NO LIME	0.25 GM. $CaCO_3$	0.5 GM. $CaCO_3$	1 GM. $CaCO_3$
16 hours	5.8	6.2	6.7	10.4
2.5 days	15.8	37.7	43.1	54.5
3.5 days	19.0	41.9	60.0	70.5
4.5 days	26.2	60.4	....	77.7
5.5 days	30.8	71.8	81.3	83.8
7.0 days	34.5	66.5	84.6	87.5
7.5 days	40.5	73.6	85.7	88.3
11.0 days	52.6	88.3	91.4	85.3

quantities of limestone were applied to the tumblers; namely, ¼-, ½-, and 1-gm. portions.

It will readily be seen that where no limestone was added, the rate of decomposition of the urea was slowed up greatly, and even at the end of 11 days, only about 50 per cent of the nitrogen was converted to ammonia. The

application of the ½-gm. portion of limestone per 100 gm. of soil seemed to bring about the most rapid decomposition of the urea; 81.3 per cent of the nitrogen was converted to ammonia in 5½ days and 91.4 per cent in 11 days.

SUMMARY

The object of this paper has been to study the relative availability of garbage tankage and urea in comparison with other organic and inorganic nitrogenous fertilizers, and to study the rate of decomposition of urea under various conditions.

Vegetation experiments were carried on in pots with sand cultures. Three crops were grown: barley, rape, and sorghum.

Comparisons of the various fertilizers are discussed under the headings: Yield of dry matter, percentage of nitrogen in the crops, percentage of nitrogen recovered in the crops, and the relative availability of each.

It was found that the fertilizing value of garbage tankage was very low. Most of the nitrogen which it contains is very slowly available, and its total percentage of nitrogen is also low in comparison with other forms of organic nitrogen. As a fertilizing material, its chief value will probably be in its use as a filler.

Urea was found to be a very desirable source of nitrogen and was very nearly equal to nitrate of soda in availability. In some cases the crop yield was even greater than with nitrate of soda. In all cases, it was better than sulfate of ammonia.

On the basis of 100 for nitrate of soda, urea rates 98 per cent available; sulfate of ammonia, 88.2 per cent; standard tankage, 53.4 per cent; fish, 49.2 per cent; and garbage tankage, 14.2 per cent.

Chemical availability tests were made by three different methods on three of the organic fertilizers, and were compared with the vegetation tests. The conclusion was reached that, except in a general way, not much dependence can be placed on the present chemical methods for the determination of available organic nitrogen.

The rate of the decomposition of urea was studied in cultures of sand, of a mixture of half sand and half soil, and of soil alone. The index for determining this was the amount of nitrogen converted to ammonia from the urea, over different periods of time. The cultures were maintained at room temperature. After 5 days, only 3 per cent was converted to ammonia in the sand culture, 67 per cent in the half sand cultures, and 90 per cent in the soil alone. With the soil alone, over 50 per cent was converted to ammonia within 3 days.

On an acid soil, the rate of the decomposition of the urea was very much retarded, and even at the end of 11 days, only about 50 per cent of the nitrogen was converted to ammonia.

The application of various amounts of limestone to the acid soil increased proportionately the rapidity of urea decomposition.

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PLATE 1

Fig. 1. Comparison of Different Nitrogenous Fertilizers—Barley

1. No nitrogen
2. Garbage tankage
3. Animal tankage
4. Urea
5. Sulfate of ammonia
6. Nitrate of soda

Fig. 2. Comparison of Different Nitrogenous Fertilizers—Sorghum

A. L. PRINCE AND H. W. WINSOR

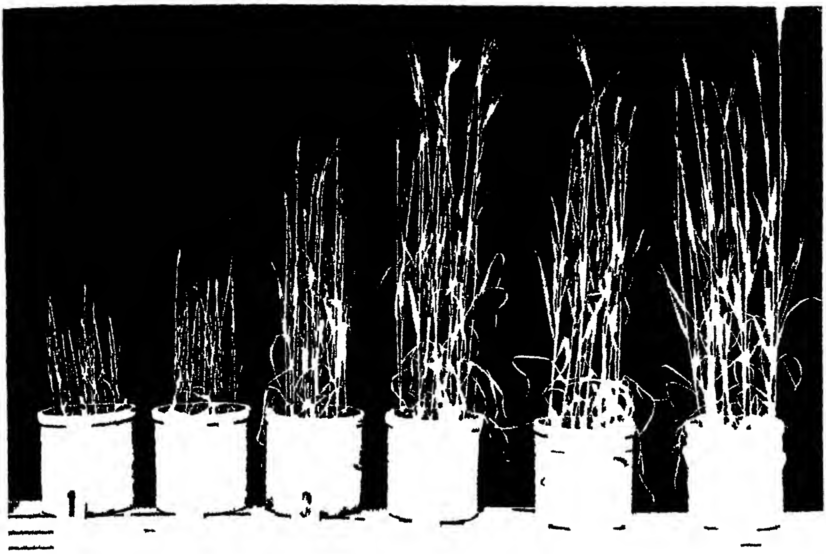

FIG. 1

FIG. 2

SOME RESIDUAL EFFECTS OF NEUTRAL SALT TREATMENTS ON THE SOIL REACTION

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More complete data concerning the chemical constitution of soils are not only a prerequisite to a better knowledge of the nature and extent of the soil reactions that take place under different soil treatments but also an aid to an understanding of the economic relationships of these reactions.

This article deals with the effects, on the soil reaction of the various horizons of four soil type profiles, of some different cations fixed by these soils from neutral salts (chlorides), after the soluble products of the soil-neutral salt reaction have been practically completely washed from the soils. It is intended to call attention principally to the results obtained on the particular soils under investigation, and also to show the remarkable agreement in the nature of these results among the different soils, which is not usually encountered in chemical soil investigations. In addition to the foregoing points, more evidence as to the possible combination of the fixed cation in the molecule of the soil compound responsible for the effects observed is set forth in this report.

SOILS USED

For this study, four types of soils were selected; namely, Miami loam, Kewanee silt loam, Nappanee silt loam, and Bellefontaine sandy loam. Typical profiles for each soil were selected.[1] The surface, or A horizon, sample was taken to a depth of 6 inches from a cultivated field adjacent to the place where the remainder of that particular profile was obtained. All the other samples are from horizons of virgin, forested soils, and were taken, not on a basis of inapplicable linear depths, but as directly representing the various well-marked soil horizons present in the several types examined. The A_2 and A_3 horizons are those of elutriation, which is brought about by the soil weathering processes, and are characterized chiefly by a relatively low content of easily soluble bases. A part, at least, of the elutriated materials from the A horizons has been concentrated in the soil portion directly beneath them and has formed the distinct soil layers designated as the B horizons. The C horizons designate the parent, or unweathered, soil material presumably as deposited by glacial

[1] Complete descriptions of these type profiles may be obtained from recent Michigan Soil Survey Reports.

action; the soil samples representing these horizons were taken at some distance below the visible zone of soil weathering.

PROCEDURE

The soil samples were dried in the air, passed through a 2-mm. mesh sieve, and thoroughly mixed to make them uniform in composition. For the soil treatments, $2N$ solutions of $CaCl_2$, $MgCl_2$, KCl, and NaCl were used, the $CaCl_2$ and $MgCl_2$ solutions being made neutral before adding them to the soils.

Six 20-gm. soil charges were weighed out for each horizon, placed into small beakers, and given the following respective treatments; check, washed check, $CaCl_2$, $MgCl_2$, KCl, and NaCl. The check sample was placed into an 8-ounce sterilizer bottle with 50 cc. of water and shaken constantly for 7 hours. The salt treated samples, which received 50 cc. each of the $2N$ salt solutions, were allowed to stand with frequent stirring, for 1 hour, then they were thrown on a filter paper and washed with water until chlorides were absent from the leachings, transferred to 8-ounce sterilizer bottles with 50 cc. of water each, shaken for 5 hours, and left to stand over night. The washed check sample of soil received the same amount of washing and the same subsequent treatment as did the salt treated samples. The following morning the hydrogen-ion concentrations of the several samples were determined by means of the hydrogen electrode.

DISCUSSION

The data are shown graphically in figure 1. The vertical lines, from left to right, represent pH values, the pH value 7 being indicated by a heavy line. Each set of six treatments represents one soil horizon. The results of the several horizons are placed in the same relative position on the graph as that occupied in the soil profile. The variation in the pH values of the various horizons and the corresponding residual effects of the neutral salt treatments are easily observable.

The washed check treatments were introduced in order to determine if the effects of washing the soil samples would be great enough to interfere with any conclusions that might be drawn from the results of the salt treatments; and it is believed that the observed effects of these treatments on the several soil samples are not due to the washing of the soils.

Perhaps the most important point in connection with this research is the consistent relationship found in the results of the four salt treatments—$CaCl_2$, $MgCl_2$, KCl and NaCl—as compared with the check treatments. The residual effects of the $CaCl_2$ treatments were small; this salt caused no great change in pH values over those of the check samples, and was less effective in changing the soil reaction than any of the other salts. Next in order of magnitude are the $MgCl_2$ effects, a consistent increase in pH values being found over the check and $CaCl_2$ treatments. The KCl and NaCl treatments

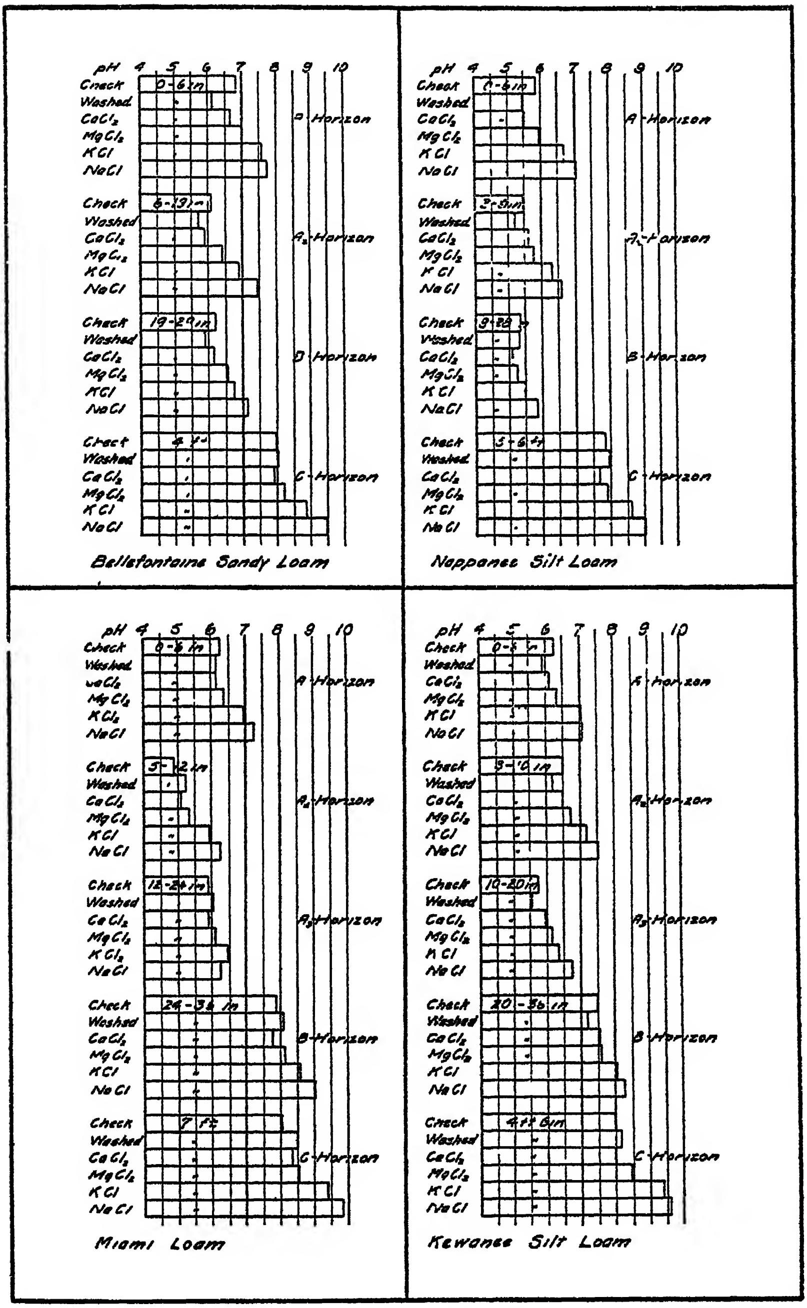

FIG. 1. VARIATION IN pH VALUES OF HORIZONS AND CORRESPONDING RESIDUAL EFFECTS OF NEUTRAL SALT TREATMENTS ON FOUR SOIL TYPES

caused marked increases in pH values in all of the horizon samples, in some cases even making acid soils alkaline in reaction; the NaCl effects were consistently greater than those of KCl. Hence, the order of the several cations with regard to their residual effects on increasing the pH values of the soils is: Ca, Mg, K, Na.

Two other points of importance are that the salt treatments produced relatively the same effects on the alkaline soil samples as on the acid samples; and that the acidity produced in soils by neutral salt treatments is soluble and can be leached readily from the soils.

Some soil investigators hold that the neutral salt cation fixed by soils is selectively adsorbed on the surface of the soil particles (colloids), thus setting free the anion of the salt, which in turn increases the hydrogen-ion concentration of the solution; whereas others claim that this reaction between soils and neutral salts is a chemical reaction involving the equivalent exchange of cations between the soils and salt. No attempt will be made here to discuss the merits of the foregoing theories, but our data tends to support the chemical theory because: (*a*) A cation relationship is shown in that the $CaCl_2$ salt caused very little change in the soil reaction; and (*b*) Since the soluble acids and other soluble products were washed from the soils, the increase in pH value is best explained on the basis of increased OH-ion dissociation due to greater solubility and hydrolysis of the soil material containing the fixed cations. In these soils, the principal reacting base is calcium; hence, when they are treated with $CaCl_2$ little exchange of cations can take place, and the soils are not markedly changed with respect to their bases or basic properties. However, when other cations, particularly potassium and sodium, are substituted for the soil calcium, marked changes in the basic properties of the soils are observed

SUMMARY

1. Soil samples from the horizons of four soil profiles were treated separately with the neutral salts $CaCl_2$, $MgCl_3$, KCl and NaCl, in order to determine the residual effect on the soil reaction after the soluble products of the soil-salt reaction were washed from the soils.

2. The $CaCl_2$ treatment caused only slight changes in the soil reaction, whereas the $MgCl_2$, KCl, and NaCl treatments increased the pH values of the soils. The effective order of the several cations is: Ca, Mg, K, Na.

3. Increased solubility and hydrolysis of the soil material containing the fixed cation are believed to be the cause of the increased pH values where increases are noted.

THE UTILIZATION OF WATER BY PLANTS UNDER FIELD AND GREENHOUSE CONDITIONS

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An understanding of the characteristic features of the utilization of soil moisture by plants during their growth period is of great importance to the farmer in the arid region, in order that he may regulate this process. The Saratov Experiment Station, therefore, during the year 1924, made parallel observations on the utilization of water by plants under field and greenhouse conditions. For this purpose, in the field experiments most of the field crops were used, whereas in the greenhouse, on account of lack of space, fewer crops—of the most representative plants—were utilized.

METHODS OF OBSERVATION

In order to investigate the utilization of the soil moisture by plants, crops on typical soils were taken, under normal conditions of culture. The following plants were used in the field: winter rye and wheat, soft and hard spring wheat, oats, and barley. From the leguminous plants the following were used: lentils, peas, and *noot;* from the grasses: sorghum, Sudan grass, and alfalfa; from the tillable and oily crops: buckwheat, corn, sunflower, potatoes, carrots, pumpkin, and flax.

In the greenhouse the following crops were used: soft and hard spring wheat, oats, buckwheat, peas, clover, flax, sunflower. For each of these plants the number of duplicate pots used was such that sampling the soils at 10-day intervals during the vegetation period sufficed. A moisture content equivalent to 60 per cent of the moisture-holding capacity was maintained during the growth period.

The plants in the greenhouse were sown at the same time as the plants in the field; the samplings were done at 10-day intervals. The portion of the plant above the ground was weighed in the wet state soon after cutting, dried, weighed again, and analyzed for ash, nitrogen, and phosphoric acid.

The daily losses of moisture as determined by comparing the weight of the pots and the plants during the growth period with the weight of the dry matter of the crop, afford a means of determining accurately the utilization of water by the plants during the different periods of growth.

[1] Translated from the Russian manuscript by J. S. Joffe, New Jersey Agricultural Experiment Station.

In the field, moisture determinations were made on corresponding days at a depth of 100 cm. over an area of 10 cm.; the crops from definite areas upon harvesting were weighed, dried, and weighed again. The crop samples were analyzed for ash and nitrogen.

METEOROLOGICAL PECULIARITIES

The vegetation period during the year was typical for the dry area around the lower Volga. The summer was exceptionally hot and dry. The rainfall during the whole period of growth of the early spring grains was very slight, but heavy showers fell on June 5. In the field the plants were growing primarily on the moisture reserve from fall and winter; for that reason the growth was far from being satisfactory and the yield therefore was diminished. The plants in the greenhouse did not suffer from a lack of moisture, but the comparatively low moisture content of the air and the high temperature had its effect on their development.

The temperature of the air in the greenhouse for the 10-day period from June 10 to June 19 was, on the average, 28.1°C.; the relative humidity of the air was, on the average, 36 per cent. This was the hottest and driest 10-day period during the growth of the wheat. The second half of the vegetation period was more favorable for growth; therefore the late tillable crops developed and gave a normal yield.

POLTAVKA WHEAT IN FIELD AND IN GREENHOUSE

The wheat was planted on April 23 and came up on May 4. Stooling was noticeable on May 19; heading out, about June 15 or 16; the crop matured about July 9 or 10. It is interesting to note that the development of the wheat in the greenhouse and in the field was absolutely identical, notwithstanding the sharp differences in the condition of their growth—heavy watering in the greenhouse, on one hand, and the typical drought of the soil in the field. Simultaneous samplings of the growing plants were made on May 20 and 30, June 9, 19 and 30, and on July 10 and 20.

To calculate the transpiration coefficient in the field, use was made of the figures on the amount of water lost from the soil as determined by difference between two successive determinations of the moisture content at the depth of 100 cm. excluding the amount of rainfall. It was supposed that the latter was fully utilized by the soil, increasing in one way or another the percentage of moisture in it. Notwithstanding the fact that a part of the water was indirectly evaporated from the soil surface, and therefore this supposition was not exactly right, there was no possibility of approaching the problem in any other way. The transpiration coefficient in the greenhouse was determined in the ordinary way, that is, by dividing the total amount of water evaporated during the growth period by the weight of the dry yields. The fundamental data on this question are given in table 1.

The data presented for the field and greenhouse experiments suggest that the processes of the growth of Poltavka wheat run very closely even under such variable conditions. Of course, with the greenhouse experiment one gets a more distinct picture of the growth and also of the various limitations, since the plants themselves and the moisture supplied are fully controlled by the experimenter. It is entirely different in the field. Even the increase of growth cannot be discounted, since no two neighboring plots ever have the same vegetation. Undoubtedly there is a similar variation in the pots, but this difference is not so great.

It is especially difficult to calculate the amount of soil water utilized by plants. In the first place it is not simple to calculate the moisture which is being evaporated from soils. There may be individual departures in different

TABLE 1

The amount of tops, utilization of water, and transpiration coefficient of Poltavka wheat in various phases of its growth

TIME PERIOD OF OBSERVATION	YIELD OF TOPS		DRY MATTER		AMOUNT OF WATER TRANSPIRED BY PLANTS: At each 10-day interval		AMOUNT OF WATER TRANSPIRED BY PLANTS: Total		WATER EVAPORATED DURING THE 10-DAY PERIOD		TRANSPIRATION COEFFICIENT	
	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse
	gm.	*gm.*	*per cent*	*per cent*	*poods*	*poods*	*poods*	*poods*	*per cent*	*per cent*		
May 20	16	1.8	31	22	39,435	508	39,435	508	28	4	3,933	282
May 30	60	5.5	25	15	23,746	1,477	63,181	1,985	17	12	2,256	362
June 9	120	13.2	27	21	16,146	3,095	79,327	5,080	12	25	1,259	384
June 19	117	21.1	44	35	34,732	3,442	114,059	8,522	25	28	1,141	402
June 30	164	23.8	52	45	21,733	2,187	135,792	10,709	16	18	823	449
July 10	79	21.5	66	69	3,693	1,445	138,485	12,154	3	12	1,395	565

soils with variable degrees of porosity. It is absolutely impossible to determine what portion of the rainfall moisture evaporates indirectly from the surface of the soil and does not take part in the processes of transpiration of plants.

To simplify matters it is necessary to take into consideration all the atmospheric precipitation, assuming that it takes part in one way or another in the formation of that portion of moisture which is found in the soil at the time of sampling.

It is interesting, however, to note that even with a crude method of calculation, very close similarity was found in the processes of transpiration in the field and in the greenhouses. Discarding the first two 10-day periods, when the plants were still small and did not cover the soil, and when the moisture.

therefore, could evaporate freely from the surface, it was found that later there was a true parallel in the evaporation from the plants in the field and in the greenhouse. With a gradual increase the transpiration of wheat reached its maximum, both in greenhouse and in field, during the 10-day period from June 9 to 19, when heading out and blooming took place.

As may be inferred from the data given, Poltavka wheat, with constant watering of the soil in the greenhouse, transpired for the 20-day period—which coincides with the formation of stems, heading, and flowering—a little more than half of all the moisture necessary (53 per cent) for its growth. For the whole month of June the wheat transpired 71 per cent of the moisture transpired for the whole vegetation period.

From this we may see clearly the significance of rainfall during May and the beginning of June: it is from this source that the wheat draws its moisture for development.

Under field conditions matters are somewhat different. Here under the conditions of drought during 1924 a great quantity of moisture from the soil was lost during the first days of the development of the wheat. The moisture so lost was unavailable for the plants; the losses came about not through the plants, but indirectly, through the soil.

If, during the first two 10-day periods of the development of the wheat in the greenhouse, only 16 per cent of the total amount of moisture necessary for this development evaporated, then the unproductive loss of water from the soil for the same period is equivalent to 30 per cent of the total amount. Under such conditions the necessity of having a large amount of soil moisture in the spring for the successful growth of wheat is sharply brought out. As the soil is being covered with plants and shaded, evaporation of moisture through the soil is prevented; at this time the amounts of water necessary for the growth of the plants both in the greenhouse and in the field are very nearly equal. The great difference in the third 10-day period when less water was apparently evaporated in the field than in the greenhouse, is explained by the fact that during this time there was a heavy downpour of rain which gave to the soil 32 mm. of water, increasing the soil water content at the time of the determination.

Much less similarity is found in the rate of growth under field and greenhouse conditions. The difficulties in taking uniform samples of plants in the field become apparent, and the growth increase in the field does not correspond to the increase in the greenhouse. Notwithstanding the greater soil moisture consumption during the period of June 9 to 19, during which an increase in growth should appear, there was none in the field, although in the greenhouse during the same period the increase was quite appreciable. A large discrepancy may be accounted for by the fact that the samples were taken when ripe. Although in the greenhouse the last sampling was somewhat larger than the one previous, in the field the last sampling was only half of the one previous; this introduces a great error.

If the decrease in dry matter of the field crop had been proportional to that

in the greenhouse, then the yield of the last sampling would have been about 150 gm.

The discrepancy in taking the field samples greatly influences the calculations of the transpiration coefficients; they cannot therefore be the same both in the field and in the greenhouse. The last two columns of table 1 give an idea of the amount of moisture necessary for plant growth in the different vegetative periods. It also gives the transpiration coefficient for the total yield.

The figures on the transpiration coefficient is the greenhouse, show that transpiration increases with every 10-day period, the matured plant doubling that for the first sampling. The data lead to the supposition that the formation of the vegetative mass of Poltavka wheat in the different periods of its growth does not coincide with the loss of moisture. The earlier portions of the plant seem to require for their formation less water than the portions which form later. As the plant is developing, each new unit of dry matter is formed with greater difficulty than the previous one.

After all, the transpiration coefficient of Poltavka wheat in the greenhouse during the year of the experiment was what it should be in a dry year.

The data on the field observations give an entirely different picture. If the weight discrepancy of the last sampling is connected in proportion to the crop from the greenhouse, the transpiration coefficient for the total yield decreases appreciably and equals about 920. The change of the unit of the transpiration coefficient in the field at maturity produces a picture in perfect contrast to that in the greenhouse. Beginning with the large figure 3900, it gradually falls at maturity and is decreased approximately four times as compared with the first value.

If the correction is not made, the transpiration coefficient in the field will be approximately two and one-half times as great in the field as in the greenhouse. With the correction for the crop, this value is decreased gradually until it is only twice as great. At any rate the utilization of water by wheat in the field during the year 1924 was twice that in the greenhouse which must be ascribed to the indirect loss of soil water, which was not taken into consideration.

The figures on the transpiration coefficient of the first 10-day period bring out this point. In the first 10-day period the wheat in the field is losing nearly 14 times as much water for each unit of dry matter as that in the greenhouse. In the next 10 days this loss is cut 2; the next, 2 more; gradually approaching to only 2 or 3 times the amount, as compared with the greenhouse. We must assume that if it would be possible to eliminate the indirect loss of water from the field soil, the utilization of water for the formation of dry matter of the crop in the field and in the greenhouse would not differ very much.

BELOTOORKA WHEAT IN THE FIELD AND IN THE GREENHOUSE

With simultaneous plantings the germination and the first phases of development of Belotoorka and Poltavka were the same. A noticeable backwardness

begins with Belotoorka during the phase of heading; Belotoorka matures 10 days later than Poltavka, and the last sampling was taken July 20. The time periods of taking the samples were the same. The data for Belotoorka are presented in table 2.

The conditions of growth of Belotoorka in the field and greenhouse, are comparable to those of Poltavka. Notwithstanding the inconsistency in the figures for the field plants, we still obtain a comparable picture for the field and greenhouse, and for the evaporation of the water from the soil.

The evaporation of water from the field soil with Belotoorka is small during the second 10-day period but is very large during the third. It is possible that there was an error in determining the moisture content of the soil.

The water requirement for Belotoorka wheat in the field and in the greenhouse was at its maximum during the first 20 days of June. In the field,

TABLE 2

The amount of tops, utilization of water, and transpiration coefficient of Belotoorka wheat in various phases of its growth

Time period of observation	Yield of tops		Dry matter		Amount of water transpired by plants: At each 10-day interval		Amount of water transpired by plants: Total		Water evaporated during the 10-day period		Transpiration coefficient	
	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse
	gm.	gm.	per cent	per cent	poods	poods	poods	poods	per cent	per cent		
May 20	4	1.6	23	19	26,835	526	26,835	526	19	7	3,354	337
May 30	15	4.8	22	15	5,266	1,284	32,101	1,910	4	17	1,107	378
June 9	28	13.6	29	22	57,306	2,739	89,407	4,549	41	37	1,687	336
June 19	75	14.9	36	42	37,252	1,802	126,659	6,351	26	24	880	426
June 30	88	16.0	45	51	3,253	966	129,912	7,317	2	13	770	457
July 9	85	18.4	61	67	6,213	105	136,125	7,422	4	1	835	403
July 19	101	16.3	63	78	4,680	40	140,805	7,462	3	5	725	458

67 per cent and in the greenhouse 61 per cent of the total for the whole period of growth were evaporated. It is worth noting that the process of utilization of water during the growth of Belotoorka is somewhat different from that of Poltavka. In the greenhouse the Poltavka up to June 1 took only 16 per cent of the total moisture necessary, while Belotoorka for the same period took 24 per cent. The maximum utilization of water by Poltavka was during the period from June 9 to 19. For Belotoorka this maximum was 10 days earlier. For that reason up to June 9, 61 per cent of the total moisture was necessary for Belotoorka whereas for Poltavka only 41 per cent was necessary. Still the development of Belotoorka was slower than that of Poltavka. Apparently

Belotoorka requires for successful growth a good deal more water in the beginning than Poltavka.

As to the accumulation of dry matter in the field, the Belotoorka was more successful than the Poltavka, consequently the transpiration coefficients for the 10-day periods were more regular. The greatest transpiration coefficient, which was in this case also during the first 10-day period, is equal to 10 times the coefficient for the greenhouse. This very clearly indicates the great loss of water from the soil under wheat during the first weeks of its development when it does not as yet shade the ground and the moisture evaporates without any hindrance from the soil surface.

After two 10-day periods the transpiration coefficient of Belotoorka drops to half; in the next 10-day period to another half; and after that it changes but little up to maturity. Because of the accuracy of sampling at harvesting, the transpiration coefficient for Belotoorka was a good deal less at this time than for Poltavka and relatively close to the calculated value of Poltavka. A comparison of the transpiration coefficient in the field with that in the greenhouse, shows that the latter was fluctuating within very small limits, gradually increasing at maturity. It is interesting to note that during the year of observation the transpiration coefficient of Belotoorka in the field and in the greenhouse was appreciably less than for Poltavka. The total amount of water evaporated during the growth period of these two kinds of wheat was the same in the field, but in the greenhouse the Poltavka evaporated more water than Belotoorka.

VICTORIA PEAS IN THE FIELD AND IN THE GREENHOUSE

Among the legumes, Victoria peas planted in the field and in the greenhouse at the same time on April 29 were observed in both places. The rate of growth of the peas in the field and in the greenhouse was the same; during June 23 and 25 both sets of plants bloomed. In the greenhouse the peas were harvested on July 22, and in the field on July 29. The data for the Victoria peas are shown in table 3.

The character of growth of the peas in the greenhouse and in the field is about the same; there is a gradual accumulation of dry matter almost to the end of the development and a slight decrease before harvesting. The pea crop in the field developed later than in the greenhouse. In the utilizaton of soil water by the plants in the field and in the greenhouse, there was very little similarity, but this must be ascribed to the method of determination, which is not at all satisfactory under field conditions. Here, just as in the previous cases, during the first interval the peas in the field lost a large amount of water on account of the indirect evaporation of water from the soil surface. Later a greater utilization of water by the field plants, especially during the first 10 days of June, was noticed. This corresponds with the blooming period of the peas. In the greenhouse the utilization of water was more regular and more or less equal during the whole period of growth. The very early and the very

TABLE 3

The amount of tops, utilization of water, and transpiration coefficient of Victoria peas in various phases of its growth

The period of observation	Yield of tops		Dry matter		Amount of water transpired by plants				Water evaporated during the 10-day period		Transpiration coefficient	
					At each 10-day period		Total					
	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse
	gm.	*gm.*	*per cent*	*per cent*	*poods*	*poods*	*poods*	*poods*	*per cent*	*per cent*		
May 22..........	4	3.5	16	16	13,507	532	13,507	532	14	2	1,688	151
June 2..........	15	7.8	18	13	6,106	3,111	19,613	3,642	6	13	676	466
June 11..........	38	13.3	17	16	40,506	3,866	60,119	7,509	41	16	847	562
June 21..........	52	21.1	24	23	9,532	5,966	69,651	13,475	10	25	697	639
July 1..........	62	33.8	52	24	9,133	4,124	78,784	17,599	9	17	662	520
July 11..........	87	44.9	32	30	4,533	4,187	83,317	21,786	5	18	500	484
July 21..........	108	36.2	45	50	4,860	1,917	88,177	23,703	5	8	426	655
July 29..........	98	....	71	..	10,330		98,507		11		524	

TABLE 4

The amount of tops, utilization of water, and transpiration coefficient of buckwheat in various phases of its growth

Time period of observation	Yield of tops		Dry matter		Amount of water transpired by plants				Water evaporated during the 10-day period		Transpiration coefficient	
					At each 10-day interval		Total					
	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse
	gm.	*gm.*	*per cent*	*per cent*	*poods*	*poods*	*poods*	*poods*	*per cent*	*per cent*		
May 30..........		0.9		8		62		62		0.4		65
June 9..........	22	15.4	15	18	23,998	2,042	23,998	2,104	22	13	571	136
June 19..........	83	19.7	19	14	21,292	3,747	45,290	5,851	20	23	285	296
June 30..........	160	41.6	28	23	41,053	3,494	86,343	9,345	38	22	381	224
July 10..........	212	52.0	32	30	5,373	3,705	91,176	13,050	5	23	226	250
July 20..........	156	78.2	30	47	1,500	2,244	93,216	15,294	1	14	312	195
July 31..........	214	80.3	35	65	1,930	738	95,146	16,032	2	5	232	200

latest phases of growth of the greenhouse peas required a small amount of water; it seems that during the period before blooming, peas require the greatest amount of soil moisture. There is a great uniformity in the transpiration coefficients of the peas both for the field and for the greenhouse conditions,

except that the greatest transpiration coefficient is during the first period of growth in the field whereas it is the smallest during the same time in the greenhouse. Later these values are not so far apart and in the final results it may be shown that the transpiration coefficient in the field is even less than in the greenhouse.

BUCKWHEAT IN THE FIELD AND IN THE GREENHOUSE

In the observations with buckwheat during 1924, the last sampling at maturity was not taken and therefore a comparison of the final transpiration coefficients of this plant at maturity is impossible. Neither were the observations for the growth and water utilization in the field and in the greenhouse made at the same time, the observations in the field being two days later. These data are summarized in table 4.

Unfortunately there was no sample at harvesting and therefore no possibility of determining the transpiration coefficient at harvesting. It is, however, very interesting to note that the transpiration coefficients of buckwheat in the field and in the greenhouse are very close, beginning with the third sampling.

As has been repeatedly shown in experiments on the transpiration coefficient of tillable plants, buckwheat belongs to the plants with a comparatively small transpiration coefficient. This was confirmed by observations in the field and in the greenhouse during 1924. The buckwheat required the least amount of water for its growth, giving at the same time a very large amount of growth at harvesting.

The utilization of water in the greenhouse was regular during almost the whole growth period, and it was only during the last 10-day period before maturity that the plants required a relatively small amount of water. It was not so regular in the field. A fairly large amount of moisture—about 12 per cent—was used by the plants during the last 10-day period (from August 1 to 11), whereas in the greenhouse during the same period only 5 per cent was used.

Notwithstanding the crudeness of the determination of the utilization of water by plants during their growth in the field, there was a chance to note very accurately the characteristic properties of buckwheat in this respect. This supports the belief of the author that by observing plants in the field it is possible more or less, although in relative figures, to notice the character of the utilization of soil water by crops. On the other hand the greenhouse experiments may serve to differentiate in series the cultural plants from the standpoint of their utilization of water even under field conditions.

SUNFLOWERS IN THE FIELD AND IN THE GREENHOUSE

Parallel observations on sunflowers grown under field and under greenhouse conditions were made, with the greenhouse plants started somewhat earlier. The ripening of the sunflowers in the field was delayed and the harvest was completed 10 days after the greenhouse crop was harvested.

Table 5 gives the data on the sunflower plants. In determining the transpiration coefficient of sunflowers, one must consider the difficulties connected with the selection of samples for the determination of the dry matter. The difficulty consists in that one must take only five to eight plants. To select more or less uniform plants every time is difficult, and therefore a series of irregular figures is obtained for the dry matter. This is particularly noticeable at the end of the vegetation period when it is necessary to deal with the large plants. It is impossible to avoid this in the greenhouse; for that reason the dry matter figures of the crop vary from time to time.

In the greenhouse there is a regular increase of the utilization of water with the growth of the plant, whereas in the field for the period from June 11 to July 22, the variations in the amount of water utilized for 20 days are not so great. In the field the great mass of water from the soil was taken in the beginning of July. After that period very little water was utilized.

TABLE 5

The amount of tops, utilization of water, and transpiration coefficient of the sunflower plant in various phases of its growth

TIME PERIOD OF OBSERVATION	YIELD OF TOPS		DRY MATTER		AMOUNT OF WATER TRANSPIRED BY PLANTS: At each 10-day interval		AMOUNT OF WATER TRANSPIRED BY PLANTS: Total		WATER EVAPORATED DURING THE 10-DAY PERIOD		TRANSPIRATION COEFFICIENT	
	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse
	gm.	*gm.*	*per cent*	*per cent*	*poods*	*poods*	*poods*	*poods*	*per cent*	*per cent*		
June 2	17	5.6	15	11	12,892	2,167	12,892	2,507	8	7	402	449
June 11	63	14.4	14	13	59,826	4,146	72,718	6,653	36	14	605	462
June 21	72	26.2	18	18	32,212	6,031	104,930	12,684	19	20	760	484
July 2	112	41.5	22	19	30,973	4,404	135,903	17,088	19	15	635	412
July 12	160	56.1	24	22	4,063	5,978	139,996	23,064	2	20	455	411
July 22	130	53.8	20	22	3,687	3,522	143,653	26,586	2	14	576	494
August 1	146	67.4	27	33	1,053	2,085	144,706	28,671	1	7	516	425
August 11	200	50.8	33	33	5,040	1,640	149,746	30,311	3	5	390	595
August 22	190	....	37	..	15,567	.....	165,313	......	9	..	454	...

The observations recorded bring out the very interesting fact—the transpiration coefficients of sunflowers, in the field and in the greenhouse are very close to each other—that the development of sunflowers requires somewhat more water in the field than in the greenhouse. The final transpiration coefficients are 595 for the greenhouse and 554 for the field.

From the figures it may be inferred that the sunflower plant requires a large amount of moisture for its development in the field. Of course this may be explained by the prolonged vegetation period, which in this case was

a month and a half greater than the vegetation period of wheat. This affords the sunflower, and other plants with a prolonged vegetation period, the possibility of utilizing the rainfall of the second half of the summer when the spring wheat ceases to develop. For that reason the yield of these plants does not depend so much upon the spring rains and soil moisture; these are not dependable in that neighborhood.

Notwithstanding the fact that the soil under the sunflower plant, generally speaking, evaporates a great amount of moisture, the transpiration coefficient of the sunflower is not so great. This may be explained by the fact that sunflowers give a large yield of tops. The figures that are available for sunflowers indicate that during the vegetation period about 75,000 poods[2] per desiatina[3] of rain water fell.

TABLE 6

The amount of tops, utilization of water, and transpiration coefficient of flax in various phases of its growth

TIME PERIOD OF OBSERVATION	YIELD OF TOPS		DRY MATTER		AMOUNT OF WATER TRANSPIRED BY PLANTS				WATER EVAPORATED DURING THE 10-DAY PERIOD		TRANSPIRATION COEFFICIENT	
					At each 10-day interval		Total					
	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse	In field	In greenhouse
	gm.	gm.	per cent	per cent	poods	poods	poods	poods	per cent	per cent		
May 22	5	0.6	15	14	10,987	310	10,987	310	11	1	1,099	508
June 2	16	3.7	23	17	33,826	2,248	44,813	2,558	35	9	1,446	697
June 11	28	7.7	22	18	19,506	4,143	64,319	6,701	20	17	1,191	874
June 21	30	12.7	36	22	17,932	6,221	82,251	12,922	18	25	1,418	1,018
July 1	33	20.3	68	25	13,333	3,756	95,584	16,678	14	14	1,518	820
July 11	27	26.2	90	30	1,173	4,871	96,757	21,549	1	19	1,861	823
July 22	..	28.7	..	33	......	3,397	......	24,946	..	14	.....	869

Calculations show that the sunflower plants evaporated during their period of growth approximately 165,000 poods of water per desiatina. Thus the sunflower had at its disposal from the precipitation about 46 per cent of the moisture required; it was forced to obtain 54 per cent from the moisture stored in the soil.

FLAX IN THE FIELD AND IN THE GREENHOUSE

Among the other oily plants for the region, flax has a certain significance, although it is not planted extensively in the district.

[2] Pood = about 36 American pounds, or 16.38 kgm.

[3] Desiatina = about 2.7 acres.

Samples of flax were taken beginning with May 21. The hot weather and the lack of rain stimulated so its growth in the field that around July 11 harvesting was necessary. The greater moisture content of the greenhouse soil retarded the development of the flax and its maturity was delayed 10 days.

Table 6 gives the data for flax.

The general trend of accumulation of dry matter of the field crop is parallel to that in the greenhouse, although, as was mentioned, the flax in the greenhouse was retarded in its growth as compared with the flax in the field. Due to the fact that the soil moisture content in the greenhouse was constant and fairly high, the greenhouse plants contained a greater amount of moisture than the field plants, which were practically dry at the time of harvest.

The accumulation of dry matter in the field plants was completed during the first 10 days of July. Simultaneously the utilization of soil water ceased. In the greenhouse the growth and utilization of water continued up to the time of maturity. Observations show that the plants in the field matured prematurely,

TABLE 7

The amount of moisture utilized and the transpiration coefficient

PLANT	IN THE FIELD		IN THE GREENHOUSE	
	Amount of moisture	Transpiration coefficient	Amount of moisture	Transpiration coefficient
	poods		*poods*	
Sunflower	165,313	554	30,311	595
Belotoorka	140,805	725	7,462	458
Poltavka	138,465	1,365	12,154	565
Peas	98,507	524	23,703	655
Flax	96,757	1,861	24,946	869
Buckwheat	95,146	232	16,032	200

were comparatively under-developed, gave a small surface growth, and consequently a very high transpiration coefficient.

In the greenhouse the plants developed normally, gave a normal yield, and yet the transpiration coefficient was very great as compared with other plants. In the transpiration coefficient, as determined by field and greenhouse experiments, flax approaches the plants with a short vegetation period. The large transpiration coefficient of flax under field conditions must be associated with the possibility of the very large evaporation of water indirectly from the soil, since flax does not cover the soil and does not protect it from the sun rays.

UTILIZATION OF WATER IN THE FIELD AND IN THE GREENHOUSE BY VARIOUS PLANTS

By comparing the figures obtained from observations on the utilization of water in the field and in the greenhouse by various plants table 7 was obtained.

If the plants were tabulated according to the diminishing value of the trans-

piration coefficient, the following two series would appear: in the field—flax, Poltavka, Belotoorka, sunflower, peas, and buckwheat; in the greenhouse—flax, peas, sunflower, Poltavka, Belotoorka, and buckwheat.

It happens that only the two extreme representatives of the two series coincide; both in the field and in the greenhouse, flax has the greatest transpiration coefficient, and buckwheat, the lowest. As to the places of the other four plants, we see almost a complete contradiction between the field and the greenhouse. The peas and the sunflowers require in the field less water than the wheat; in the greenhouse, on the other hand, wheat requires less water than sunflowers and peas.

An examination of the time of harvest of the plants in the field, shows that the early maturing plants—flax, Poltavka and Belotoorka—have the greatest transpiration coefficient, whereas the late maturing plants have the lowest transpiration coefficient. There are no indications of such a relationship in the greenhouse, here the Belotoorka and Poltavka, which were harvested early, have a lower transpiration coefficient than the plants which matured later, with the exception of buckwheat.

It has been noted alreadv that in the beginning of the growth period the transpiration coefficient for all the field plants is generally very high. This has been ascribed to the fact that there is an indirect evaporation of water from the soil itself, which does not play an essential rôle in the production of the dry matter. That this actually happens is shown by the figures for the determinations of the soil moisture during the growth period of the plants on the cropped plots as compared with the plots that had no vegetation. During the period of sprouting the moisture content of the soil of the cropped and uncropped plots was the same. In either case, the moisture content depended upon the amount of water evaporated indirectly from the soil; upon this, the plant in its first stages of growth had very little effect. The author is convinced that the increase of the transpiration coefficient for the early maturing field plants may be explained by these circumstances. Of course for other plants too the same condition is observed in determining their moisture requirements during the first periods, but for plants with a long vegetation period, soil moisture evaporation does not play a great rôle. Besides, these develop faster than wheat, shade the ground earlier, and prevent the indirect evaporation of soil water.

If it were possible methodically to exclude the indirect evaporation of water from the soil surface, the transpiration coefficients for the field and greenhouse would approach each other. But this would have theoretical value only. In the field, conditions cannot be changed; a large mass of water must be evaporated indirectly from the soil, which must be taken into consideration in practical wheat culture.

It should be noted that the quick maturing plants—wheat, flax—give in the field and in the greenhouse the least amount of tops as compared with the other plants, which naturally would influence their coefficient.

In the field observations the transpiration coefficients for different plants were calculated on the basis of the amount of rainfall between periods of the observations. As has been said, the sum total of this rainfall was not discounted separately, but since it probably influences the moisture content of the soil, it ought to be taken into consideration.

On account of the variations in the growth period of the plants they receive an unequal amount of rainfall, the late maturing plants naturally receiving more than the early maturing. Thus the flax from its sprouting period to the time of harvest receives altogether per desiatina 31,200 poods of rainfall; Poltavka, 36,000; Belatoorka, 50,000; peas and buckwheat, 68,300. and sunflowers, 74,600.

If the total amount of rainfall were taken up by the soil and then utilized for plant development, the amount of such moisture utilized by the different plants for their growth would comprise the following: Poltavka, 26 per cent; flax, 32 per cent; Belatoorka, 36 per cent; sunflowers, 45 per cent; peas, 70 per cent; buckwheat, 72 per cent. The order of plants in this respect is almost identical with that of the transpiration coefficient in the field, with the exception that Poltavka and flax change places.

The remainder of moisture necessary for the plants must have been taken from the soil sources that were present at the time of planting. Undoubtedly a certain portion of the rainfall did not participate in the life processes of the plants: it evaporated indirectly from the soil surface under the influence of the sun rays. This brings out more clearly the importance of the moisture resources of the soil in the spring. It is clear that the quickly maturing plants must have for their successful growth great resources of soil moisture; their successful growth may be taken care of otherwise only by a large amount of rainfall during their growth period. At the same time it becomes clear why cultivated plants with a long vegetation period are successfully grown in this arid district; there is always the chance that a large portion of the required moisture will be covered by the rainfall, which is usually more constant in July and August than in May or June.

WINTER RYE AND WHEAT IN THE FIELD

On account of the difficulty in conducting moisture requirement experiments in the greenhouse, the number of plants studied under such conditions was limited; in the field it was possible to observe a good many plants—winter rye and wheat, corn, sorghum, potatoes, carrots, hay like alfalfa, and others —for which there were no parallels in the greenhouse. The data of only a few of these plants will be considered. To these belong winter rye and wheat on which observations were made from April 20 to July 8 when the winter rye was harvested, and to July 12 when the wheat was harvested. For the winter rye the soil gave up approximately 99,000 poods of water per desiatina. The amount of rainfall per desiatina for this period was 36,000 poods. Thus the winter rye could utilize from the rainfall only 37 per cent of the water necessary

for its growth; it approaches in this respect the earlier spring crops. The transpiration coefficient of winter rye was determined as 545.

The rate of the utilization of water by winter rye was not uniform throughout its growth. Especially large was the utilization of water during the 10-day period from May 23 to June 3—during the time of tube formation to complete heading out when the rye required approximately 36 per cent of the moisture necessary for its growth. During the next 10-day period only 27 per cent of the soil moisture was utilized. During these two 10-day periods the greatest increase in growth of the rye—a total of 86 per cent—was noticeable. Although these figures may not be very accurate, one can judge the rate of accumulation of dry material during crop growth.

For winter wheat the rate of utilization of soil water was very close to that of rye. Of the water necessary for the growth of the winter-wheat—128,500 poods—only 36,000 poods or 28 per cent came in the form of rainfall. The wheat was forced to obtain three-fourths of its moisture from the soil resources present there at springtime. The maximum utilization of soil water by the wheat was the same as for the rye. For the two 10-day periods from June 3 to 23, the winter wheat utilized 58 per cent of all the moisture taken from the soil; after that it utilized relatively very little soil water.

The period of heading out was the most productive in the sense of formation of dry matter of the crop. The final transpiration coefficient for the winter wheat at the time of harvest was 706.

CORN AND SORGHUM IN THE FIELD

Both corn and sorghum are famous for their prolonged period of growth—they were harvested September 5. Since these plants develop very slowly during the first weeks of their growth, the observations were taken in the beginning of June. During this period the soil under corn lost 147,000 poods of water and under the sorghum, 180,800 poods. The rainfall during this time amounted to about 95,000 poods per desiatina. Thus corn could replenish from the rainfall resources as high as 64 per cent of the moisture necessary for its development, and sorghum, about 53 per cent. During the following two 10-day periods from July 3 to 24, corn lost 37 per cent of all the moisture utilized, sorghum lost about 30 per cent. For the corn this period of intensified loss of water coincided with the blooming and the beginning of the filling out of the grain; with the sorghum it coincided with the formation of the head. These periods of intensified utilization of water coincided with the periods of intensified accumulation of dry matter in both plants. During the remaining period of growth, utilization of water was relatively regular.

The final transpiration coefficient for corn is 533; for sorghum, 282. There is reason to believe that the final transpiration coefficient for corn is somewhat too high, since the weight of the dry matter at harvest was found to be lower when taken at earlier periods. Since in securing samples of corn only one or two plants can be taken, errors in picking the plants for sampling are always

possible, and this has its effect on the transpiration coefficient, which in the long run is a result of the division of the total loss of moisture by the weight of the dry matter of the crop. But even in the uncorrected form, the transpiration coefficient of corn and especially that of sorghum is very characteristic.

For potatoes and carrots the greatest amount of growth must be ascribed to the moisture due to rainfall. Thus for potatoes the soil gave up 145,700 poods of water per desiatina, whereas the amount of rainfall during its growth was equal to 129,700 poods, that is, 89 per cent of all the moisture utilized by the potatoes may be attributed to rainfall. For the carrots the figures are somewhat lower; namely, 73 per cent. Utilization of soil water by both of these plants was regular and was not in any way peculiar during a particular 10-day period. The same regularity was observed in the accumulation of the dry matter of the crop..

The final transpiration coefficient for the potatoes was 441; for carrots, 549.

The data of the field observations on the utilization of water by various cultivated plants during 1924 corroborated the fundamental thought expressed on the value of the sources of moisture at the time of planting for the various spring crops and the importance of May rainfall for these plants, and emphasized especially the character of the utilization of water by cultivated plants which are more suited for conditions of rainfall distribution during the vegetation period in that district.

CONCLUSIONS

Under the conditions of the dry year of 1924, the study of the problem of the utilization of water by plants under field and under greenhouse conditions established the fact that the general character of the utilization of water is very similar under the various conditions, but the difficulty of such investigation in the field somewhat obscures the similarity.

1. Under the conditions of this investigation larger amounts of moisture are utilized during the first part of the vegetation period in the field than in the greenhouse. The loss of moisture must be ascribed to the indirect evaporation of water by the soil alongside the plants, something which does not take place in the greenhouse. Therefore, the transpiration coefficients of all the plants in the field are comparatively higher than in the greenhouse during the first part of the vegetation period.

2. This unavoidable loss of water indirectly by the soil during the vegetation period in the field leads to the conclusion that the transpiration coefficient in the field is always greater than in the greenhouse. The isolated cases of a larger transpiration coefficient in the greenhouse then in the field cannot be satisfactorily explained.

3. For the majority of the early spring crops the utilization of water during the growth period is not regular; there are specific periods when the plants put a greater demand on the soil for the moisture. With grain crops this period coincides with the period of heading out and blooming.

4. Utilization of water by seed plants like corn, sorghum and buckwheat, is more regular, but there are certain periods which are outstanding because of greater utilization of moisture.

5. The plants with a long vegetation period—the roots and tubers—are utilizing the soil moisture with a great regularity during the whole period of their growth; no intensified utilization of water at any period was noticed.

6. The relation of the various groups of plants to the soil moisture resources at the time of planting and to the rainfall during the summer is therefore entirely different. Whereas the early maturing grain crops have to depend for their development on the soil water resources, the late maturing plants may utilize the rainfall during the whole vegetation period and thus not be depending so much on the soil resources stored from the spring. The necessity of a thorough preparation of the soil in the fall for planting the early spring crops is very evident from this standpoint. Apparently the fall preparation of the soil will have less effect on the later plants.

7. Notwithstanding the fact that these data cover only one year, and that these observations must be continued in order to obtain more substantial conclusions, the author feels that the results of the work reported present a certain interest, since the year 1924, which has just expired, was a typical dry year for the region of the lower Volga.

THE VIABILITY OF THE NODULE BACTERIA OF LEGUMES OUTSIDE OF THE PLANT III, IV, V[1]

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This paper reports the results of a continuation of studies of the nodule bacteria of legumes presented in a previous paper, and has for its purpose the determination of the effects of certain factors upon the life and growth of these organisms in the soil and in artificial media.

PART III—FACTORS INFLUENCING THE GROWTH OF B. RADICICOLA

This investigation was conducted in order to study causes of failure with liquid cultures.

Methods employed

The culture used in the succeeding experiments was *B. radicicola* of garden pea, transferred from pure stock to an 8-ounce culture bottle containing mannite agar media freshly made. The age of the culture at time of using was 20 days.

In order to determine the effect of various temperatures, the refrigerator at 10°C. and the incubator at 25° to 28°C. were chosen for storage purposes.

Platings were made at different intervals as indicated in the experiments. The dilution used for plating was from 1–100 to 1–10,000,000. In order to verify the results of the bacterial count, tests for inoculation were conducted. The inoculation was made at the time of plating. It was on the basis of 1 pint of bacterial infusion per bushel of seed, having approximately 150,000 seeds (garden pea).

Experiment 9—The effect of dilution and storage

Three bottles having vigorous growth of *B. radicicola* of garden pea were mixed together and diluted to 3 pints with sterile tap water. This volume was divided into three equal portions and each portion treated differently. To the first portion nothing was added; the second portion was diluted to 1 quart; and the third to 1 gallon. Each dilution was divided into 4 equal portions and put in Erlenmeyer flasks, 2 provided with cotton plugs and the

[1] Portion of a thesis submitted to the faculty of the University of Illinois in partial fulfillment of the requirements for the degree of Doctor of Philosophy. Parts I and II were published in the preceding issue of Soil Science.

other 2 with rubber stoppers. A flask with rubber stopper and one with cotton plug from each dilution were placed in the refrigerator and the other flasks were placed in the incubator.

After the 94-day plating, 0.4 gm. of mannite sugar dissolved in 5 cc. of sterile distilled water was added to containers A, A′c, B, B′c, C, and C′c.

Experiment 10—The effect of cane and mannite liquid media

Each of four 8-ounce bottles was filled with 80 cc. of sterile liquid media and inoculated with 1 cc. of bacterial infusion containing approximately 54

TABLE 1

The effect of dilution and storage upon the number of B. radicicola of garden pea—Experiment 9

CONTAINERS*	TIME OF STORAGE PRECEDING BACTERIAL COUNT									
	Immediate	5 days	10 days	30 days	42 days	60 days	70 days	94 days	106 days	142 days
	millions	*millions*	*millions*	*millions*	*millions*	*millions*	*millions*	*millions*	*millions*	*millions*
A	19.250	60.00	68	60	33	11.0	8.0	6.00	5.200	
Ac	18.750	92.00	80	84			26.0	21.00	5.500	
A′	17.800		149	143	120	100.0	80.0	92.00	91.000	56
A′c	18.000	169.00	164	161			110.0	65.00	47.000	5
B	9.800	108.00	Many	59	42	13.0	10.0	9.00	4.150	
Bc	8.600	95.00	132	40			20.0	10.00	1.000	
B′	9.600	204.00	133	169	164	100.0	80.0	80.00	23.000	17
B′c	9.800	171.00	120	135			100.0	72 00	30 000	7
C	2.290	29.00	40	23	16	1.1	0.3	0.02	0.010	
Cc	3.000	28.95	42	22			5.0	4.00	2.000	
C′	1.930	59.00	49	44	38	20.0	14.0	17.00	24.000	1
C′c	2.250	44.00	61	58						

* A contained 1 pint, with cotton plug.
B contained 1 quart, with cotton plug.
C contained 1 gallon, with cotton plug.
"Prime" indicates refrigerator for storage.
Small "c" indicates container with rubber stopper.

million bacteria per cubic centimeter. The organisms were incubated at 26°C. and bacterial counts were made at 5, 10, 20, 30, and 40 days. After the fortieth day count, the bacterial infusion from each bottle was diluted to 1 quart and used for inoculation test.

Experiment 11—The effect of oxygen supply upon the growth of B. radicicola in solid and in liquid media

Regular mannite media was prepared, except that in the case of liquid media agar-agar was omitted. Both liquid Erlenmeyer flasks and solid media, 80 cc. of the former and 50 cc. of the latter were kept in 100 cc. After the

media had been sterilized and allowed to cool for a few days, 1 cc. of *B. radicicola* infusion of garden pea was transferred to each flask. Immediately after the transfer, some of the flasks were made air-tight by inserting rubber stoppers and sealing with paraffin. The organisms were incubated at 26°C. and bacterial counts and tests for nodule production were made at 10, 20, and 30 days. For bacterial counts, 1 cc. of bacterial infusion from solid media was diluted to 10 cc. with sterile tap water, and then a sample was taken from that diluted infusion. For the inoculation test in this experiment, 1 cc. of bacterial infusion from either media was used to inoculate 5 sterile seeds.

TABLE 2

The effect of cane and mannite liquid media upon growth of B. radicicola of garden pea—Experiment 10

Bacterial counts

MEDIA	PLATINGS AFTER					INOCULATION TEST 40 DAYS
	5 days	10 days	20 days	30 days	40 days	
	millions	*millions*	*millions*	*millions*	*millions*	
Mannite..........................	36	127	79	112	80	Many nodules
Cane..............................	25	45	32	4	3	Few nodules

TABLE 3

The effect of shaking upon the growth of B. radicicola—Experiment 12

Bacteria count

CONDITIONS	AMOUNT OF MEDIA	INITIAL COUNT	PLATINGS AFTER		
			4 days	24 days	30 days
	cc.		*millions*	*millions*	*millions*
Shaken.....................	(a) 100	380,000	60	210	120
	(b) 200	865,000	30	140	50
Not shaken................	(a) 100	1,650,000	65	60	40
	(b) 200	900,000	40	20	20

The counts after 10, 20, and 30 days showed that organisms were totally absent from both the solid and liquid media provided with rubber stoppers, where the dilution was 1–10,000 per cubic centimeter. The organisms grown in similar media but with the flasks plugged with cotton were alive and had multiplied greatly, 243 million for solid and 45 million for liquid being found per cubic centimeter at 10-days growth.

Very few nodules were found as the result of inoculation with the infusion from the sealed flasks containing either kind of media. But very abundant nodule production was obtained from the inoculation with the infusion from flasks with cotton plugs. No difference was observed between the solid and liquid media in regard to nodule production.

The results of this experiment seem to indicate that lack of oxygen may be the cause of the organisms surviving for so short a period. Therefore, the following experiments along this line of attack were undertaken.

Experiment 12—Effect of shaking upon growth of B. radicicola

In this experiment, four 8-ounce bottles were used as containers. Two of these bottles received 100 cc. each, and the other two, 200 cc. each, of the media. After the media had been sterilized and allowed to cool for a few days, the organisms were introduced. The inoculation of this media was on the basis of 1 cc. of the infusion of *B. radicicola* of garden pea to 100 cc. of the media. The organisms were incubated at 26°C. One bottle containing 100 cc. and

TABLE 4

Oxygen as a limiting factor during the growth of B. radicicola of garden pea 'n mannite liquid media—Experiment 13

CONDITIONS	PLATED AFTER	PLATES	DILUTION		COLONIES IN PLATES	BACTERIA PER CUBIC CENTIMETER	NODULES PRODUCED
	days						
Original infusion.....	Initial	E	1–1	million	15	15 million	Many
Cotton plug..........	4	E	1–1	million	25	25 million	Many
Rubber stopper.......	4	E	1–1	million	2	2 million	Few
Cotton plug..........	7	F	1–10	million	7	70 million	Many
Rubber stopper.......	7	F	1–10	million	1	10 million	Few
Cotton plug..........	11	F	1–10	million	5	50 million	Many
Rubber stopper.......	11	E	1–1	million	19	19 million	Several
Cotton plug..........	15	E	1–1	million	115	115 million	Many
Rubber stopper.......	15	E	1–1	million	25	25 million	Many
Cotton plug..........	20	F	1–10	million	17	170 million	Many
Rubber stopper.......	20	E	1–1	million	14	14 million	Several
Cotton plug..........	23	F	1–10	million	16	160 million	Many
Rubber stopper.......	23	B	1–1,000		5	5,000	Scant
Cotton plug..........	27	F	1–10	million	17	170 million	
Rubber stopper.......	27	C	1–10,000		17	17,000	
Cotton plug..........	34	F	1–10	million	3	30 million	Many
Rubber stopper.......	34	B	1–1,000		5	5,000	Scant

one containing 200 cc. were shaken once a day, whereas the other two were left undisturbed. In order to facilitate the shaking and to introduce more oxygen in the liquid without its touching the cotton plug, the bottle was unplugged, flamed, and the solution was stirred with the flamed glass rod. Platings were made immediately after the solution was inoculated and also at 4, 24, and 30 days. Tests for nodule production were also conducted.

Experiment 13—The effect of oxygen supply upon the growth of B. radicicola

This experiment was conducted with the idea gathered from the results of previous experiments, that oxygen in a limited amount is the factor concerned during the growth of *B. radicicola* of garden pea in mannite liquid media.

In each of fourteen 100-cc. Erlenmeyer flasks, 80 cc. of mannite liquid media was placed. An excess of calcium carbonate was added before sterilization to eliminate the possibility of the production of acidity during the process of growth. The media was sterilized in the usual manner and then cooled before the organisms were transferred into it. Each flask was inoculated with 1 cc. infusion of *B. radicicola* of garden pea. In order to limit the amount of oxygen in the media, some of the flasks were provided with rubber stoppers and sealed air-tight with melted paraffin, whereas other flasks were left with cotton plugs. The organisms were incubated at 26°C. and bacterial counts were made after 4, 7, 11, 15, 20, 23, 27, and 34 days. In order to prevent the introduction of oxygen into the media, separate flasks were used for each count; that is, after a sample for plating was taken, the bacterial infusion was discarded and new infusion was used for the next plating. Test for inoculation was also carried out at every plating.

TABLE 5

The effect upon B. radicicola of calcium carbonate and tricalcium phosphate—Experiment 14

CHEMICALS USED	AMOUNT OF MEDIA	PLATINGS AFTER					
		Initial	5 days	10 days	19 days	25 days	32 days
	cc.	*millions*	*millions*	*millions*	*millions*	*millions*	*millions*
Tricalcium phosphate	(a) 100	1.3	45	90	20	40	44
	(b) 200	1.4	70	90	21	30	33
Calcium carbonate	(a) 100	1 3	60	90	40	110	86
	(b) 200	1 4	70	80	40	100	98

Experiment 14—The effect of calcium carbonate and tricalcium phosphate

Two 8-ounce bottles were filled each with 200 cc. of the media, and 2 with 100 cc. To each of 2 bottles, one containing 100 cc. media and the other 200 cc., $\frac{1}{10}$ gm. of tricalcium phosphate was added, while to each of the other 2 bottles $\frac{1}{10}$ gm. of calcium carbonate was added. These chemicals were added to the liquid media before sterilization. After the media had been sterilized and cooled for a few days, *B. radicicola* organisms were transferred to it; the inoculation of the media was at the rate of 1 cc. of bacterial infusion to 100 cc. of sterile media.

Discussion of results of experiments 9, 10, 12, 13, and 14

In experiment 9 the count after immediately plating showed that each of the containers C, Cc, C′, C′c, which is a dilution of 1 gallon, had approximately one-eighth as many organisms as in each of the containers A, Ac, A′, and A′c, a dilution of 1 pint. Likewise, each of the containers B, Bc, B′, and B′c, of 1-quart dilution, had approximately one-half as many as the pint dilution.

This result shows that the organisms were very well distributed in the liquid, and it also showed that the dilution in regard to the number of organisms in a given volume was approximately correct.

After 5 days storage, the bacterial count varied, irrespective of dilution, as for example the container A, a dilution of 1 pint, had 60 million per cubic centimeter, while the container C, a dilution of 1 gallon, had 29 million per cubic centimeter. If the rate of growth were the same in both cases A should have 232 million per cubic centimeter if C had 29 million per cubic centimeter, or C should have 7.5 million per cubic centimeter if A had 60 million per cubic centimeter. This would also be true in case of dilution B. However, B had 108 million per cubic centimeter against 60 million of A.

After 10 days, A had 68 million organisms per cubic centimeter, B had many millions, and C had 40 million per cubic centimeter. Ac had 84 million per cubic centimeter against 132 million of Bc, while Cc had 40 million as against 84 million of Ac. With respect to temperature, dilution in group A had given the following count: Container A with cotton plug stored in incubator had 68 million organisms per cubic centimeter, Ac with rubber stopper stored in incubator had 80 million per cubic centimeter, A′ with cotton plug stored in refrigerator had 149 million per cubic centimeter, and A′c with rubber stopper had 164 million per cubic centimeter. The same result was also obtained in the group C; however, this was not true in case of group B.

The 30-day plating showed that in all cases, the number of organisms per cubic centimeter had decreased, with the exception of containers B′ which had increased from 133 at 10 days to 169; however, it dropped when compared with 204 million per cubic centimeter at the 5-day plating; and container B′c had results similar to B′. The figures show that in all cases, with the exception of the two containers mentioned above, the maximum amount of growth was reached between the tenth and thirtieth days and from that time the organisms began to die out, but the decrease was more significant in the A group than in the B or C group. Likewise, in all three groups, A, B, C, the organisms in the container stored in the incubator died faster than those in containers stored in the refrigerator. At the end of 142 days storage, the count showed that the total organisms in each case had decreased to approximately one-half the original number.

After the ninety-fourth day plating, as it was thought that a supply of carbohydrate might stimulate growth, mannite, $\frac{1}{4}$ gm. dissolved in 5 cc. of sterile distilled water, was added to each of the containers A, A′c, B, B′c, C, and C′c. Plating was made 12 days after, and the count showed that a considerable decrease had resulted, except in C′, which increased from 17 to 24 million.

The test for inoculation accompanying the immediate plating showed abundant nodule production in the A and B groups, but in the C group, the production was very much less. From the 5-day to the 70-day incubation, the nodules produced in all cases were very abundant, then the C group began to decrease after 94 days.

In order to ascertain that each colony counted in plates was a *B. radicicola* of garden pea, tests in milk, on potato, and for inoculation were conducted on a plate containing 11 colonies, plated from container A′c. A transfer from each colony growing in the plate was made to a tube of mannite agar slant where it was allowed to grow for 2 weeks before testing. In 11 tubes of sterile milk after 16 days there was a growth which was typical of *B. radicicola* of garden pea when grown in milk, as described by Löhnis and Hansen (1). The test in potato also verified the organism as *B. radicicola* of garden pea. When the content of each of the 11 tubes was used for inoculation, nodule production was obtained.

In experiment 10, it was found that mannite media was more favorable for the growth of *B. radicicola* than cane sugar media. However, no material difference was noticed between solid and liquid media. These results were verified by the inoculation test.

The results of experiment 12 show that organisms had multiplied more in the bottles which were shaken than those in the unshaken bottles. The difference was not noticed in the early plating, but at the 24- and the 30-day platings, the shaken bottles of both volumes contained almost four times as many bacteria per cubic centimeter as the unshaken bottles of corresponding volume. It was also noticed that in both cases, shaken or unshaken, the volumes of greater depth had given fewer bacteria per cubic centimeter than the volumes of less depth. This result showed without question that oxygen was the cause of the depression of growth. As in the case of the shaken bottles, oxygen was supplied more or less in proportion to the demand of the organisms, but this method of supplying was not highly efficient in the case of greater depth, because for instance, in the 200 cubic centimeter of media the stirring was not as thorough as in 100 cc. Besides, the rate of diffusion of air was slower in the greater depth than in the lesser depth, because of greater backward pressure of the liquid. In other words, the amounts of oxygen introduced by stirring and by diffusing were not enough either for reproduction or for protection against any toxic products developed as the result of the activity of the organism during the life process.

No difference in nodule production was observed between the two conditions under which the *B. radicicola* of garden pea was grown; this was due to the fact that more than enough organisms were present to produce abundant nodules for the plant.

Results obtained from experiment 13 showed that the organisms with a limited amount of oxygen decreased from 15 million to 2 million per cubic centimeter within 4 days, whereas those with excess oxygen had almost doubled in number in the same length of time. The organisms with excess oxygen continued to increase up to 170 million, whereas those grown in a limited amount of oxygen had decreased very considerably, to as low as 5,000 per cubic centimeter. This result was verified by the nodule production test.

It was found in experiment 14 that calcium carbonate was very much more

favorable for the multiplication of *B. radicicola* of garden pea than was tricalcium phosphate. However, the difference was not noticed until after 19 days growth in the media. The highest number in either 100 cc. or 200 cc. ever reached by the organisms grown in media containing tricalcium phosphate was 90 million per cubic centimeter. This occurred at the 10-day plating, and from that time on, the number began to decrease. But on the other hand, the organisms grown in media containing calcium carbonate reached 110 million and 100 million per cubic centimeter in 100 cc. and 200 cc. respectively. This maximum growth occurred at a later stage of the growing period, 25 days after inoculation. In all cases, either in media containing tricalcium phosphate or calcium carbonate, the 100-cc. volumes gave higher results on the average. This difference, however, did not begin to show up until the 10-day plating. At the 5-day plating, the result was reversed, the 200-cc. volumes having more bacteria per cubic centimeter than the 100-cc. volumes.

PART IV—THERMAL DEATH POINT IN SOIL AND ON ARTIFICIAL MEDIA

Methods employed

The tubes were made as follows with 6 mm. of soft glass tubing: One-third of a 1-foot length, was heated over a blue flame, drawn to a capillary size and bent in U-shape with a capillary stem one-third as long as the larger stem. The ends were sealed by heating them over a blue flame, thereby creating a sterile vacuum inside of the tube. Just before using, the end of the larger stem was cut off with a heated three-cornered file. The cut end was heated over a flame and a cotton plug was inserted while it was hot.

One cubic centimeter of an infusion containing organisms was delivered with a sterile 1-cc. pipette into the tube through its larger stem, by removing the cotton plug, which was returned as soon as possible. The tip of the capillary stem was broken off with heated pincers, thereby allowing the infusion to flow as far down in the tube as desired, when the tip was again sealed. The tube containing the infusion was attached to a standard thermometer immersed in sterile tap water in an Erlenmeyer flask. The water was constantly stirred with a stirring rod in order to keep the temperature uniform throughout the entire volume. The temperature was lowered by the application of ground ice, and raised by the application of a direct flame at the bottom of the flask. In all cases, the immersed tube was held in water for 10 minutes at every temperature, 0, 10, 20, 30, 40, 50, 60, and 70°C. The contents of the tube were removed either by breaking the capillary end or by removing the cotton plug from the larger stem. In case of soil, no special apparatus was used in transferring it to the capillary tube; however, all the necessary precautions were used in order to avoid any possible contaminations.

Experiment 15—Thermal death point of nodule bacteria, B. radiobacter and Azotobacter chroococcum

The results as reported in table 6 show that *Bacillus radiobacter* and *Azotobacter chroococcum* were alive at 50°C. for 10 minutes exposure, but all died at a

60°C. exposure for 10 minutes. *Bacillus radicicola* of garden pea and of sweet closer and *Ps. radicicola* of cowpea were alive at 40°C. for 10 minutes exposure, but all died at a 50°C. exposure for 10 minutes. Zipfel (2) reported that the thermal death point of *B. radicicola* was 60°C. to 62°C. for 5 minutes exposure.

After having found the thermal death point of the organisms, the percentage dead or alive at the highest temperature at which they were found to live was determined. The determination was made in two ways: one was by diluting the treated infusion to the dilutions desired and plating out from them, and the other by diluting the untreated infusion and transferring from each dilution 1 cc. to the capillary tube, where it was subjected to the temperature desired.

The platings made from dilutions of treated infusion of *B. radicicola* of garden pea, showed that after being held at 46°C. for 10 minutes, only approximately 4.5 per cent out of 100,000,000 bacteria were alive, and at 47°C. for 10 minutes, only approximately 0.04 per cent were alive. The platings made from infusion in the second determination showed that *Bacillus radicicola* all died at 46°C. for 10 minutes exposure.

TABLE 6

Thermal death point of nodule bacteria, B. radiobacter, and Azotobacter chroococcum in infusion—Experiment 15

ORGANISM	AGE OF INFUSION	TIME OF EXPOSURE	TEMPERATURE			
			40°C.	50°C.	60°C.	70°C.
	days	*minutes*				
Garden pea	5	10	+	–	–	–
	20	10	+	–	–	–
Sweet clover	5	10	+	–	–	–
	20	10	+	–	–	–
Cowpea	5	10	+	–	–	–
	20	10	+	–	–	–
B. radiobacter	5	10	+	–	–	–
	20	10	+	+	–	–
Azotobacter	5	10	+	+	–	–
	20	10	+	+	–	–

Experiment 16—The effect of different kinds of soil upon the thermal death point of legume organisms

In this experiment peat and brown silt loam were used. Portions of 10 gm. of each were carefully crushed up to free them from coarse particles and then placed in 40-cc. Erlenmeyer flasks with cotton plugs. After the flasks were sterilized and cooled for a few days, *B. radicicola* infusion of 10 days growth in

mannite agar, was transferred into them. The inoculation of these soils was at the rate of 1 cc. infusion to 10 gm. of sterile soil. The first thermal death point determination on *B. radicicola* in soil was made after 3 days and the second after 6 days. After the second determination, the soils were stored in the laboratory drawer and 6 months later they were used to inoculate sterile

TABLE 7

Number of organisms surviving at temperatures near the thermal death point—Experiment 15

TIME OF IMMERSION	TEMPERATURE	PLATE*	NUMBER OF COLONIES	BACTERIA ALIVE	
minutes	*°C.*				
Plating from dilution of treated infusion of B. radicicola of garden pea					
10	46	A	Many	Many	4.5 per cent
10	46	B	Many	Many	
10	46	C	50	5 million	
10	46	D	4	4 million	
None	Unheated	A	Many	Many	
None	Unheated	B	Many	Many	
None	Unheated	C	Many	Many	
None	Unheated	D	100	100 million	
10	47	A	Many	Many	0.04 per cent
10	47	B	4	40,000	
10	47	C	None	None	
10	47	D	None	None	
Plating from treated dilution of infusion of B. radicicola of garden pea					
None	Unheated	A	Many	Many	
None	Unheated	B	Many	Many	
None	Unheated	C	Many	Many	
None	Unheated	D	100	100 million	
10	46	A	None		
10	46	B	None		
10	46	C	None		
10	46	D	None		

* Dilution A = 1–1,000.
Dilution B = 1–10,000.
Dilution C = 1–100,000.
Dilution D = 1–1,000,000.

seeds. The inoculation was at the rate of 1 gm. of soil to 14 gm. of seed. In order to determine further whether the organisms in the soils were totally dead, the remaining soils of each kind were used to inoculate 5 seeds. These treated soils were tested for acidity with Richorpoor solution.

Both determinations showed that *B. radicicola* of garden pea were alive in

peat after being subjected to 50°C. for 10 minutes. In the second determination, when the inoculated soils were 6 days old, the organisms in brown silt loam were totally dead. In peat, the number of bacteria decreased very considerably. A test at this time indicated that the brown silt loam was acid whereas the peat was not.

The nodule production test showed that the nodule bacteria of garden pea were alive after seven months in peat and were able to produce nodules, but nodules were absent as the result of inoculation with the brown silt loam. This was noticed in six- and in seven-month inoculations.

TABLE 8

The effect of different kinds of soils upon the thermal death point of B. radicicola of garden pea

SOILS	TIME OF IMMERSION	TEMPERATURE	BACTERIA ALIVE	ACIDITY	TEST FOR NODULE PRODUCTION	
					After 6 months	After 7 months
	minutes	*°C.*				
First determination (1 gm. soil)						
Original infusion	None	Room	Many	None		
Mannite	10	50	None	None		
Peat	None	Room	114,000,000	None	Abundant nodule production	Several nodules were found
	10	50	450,000	None		
Brown silt loam	None	Room	16,000,000	Acid	None	None
	10	50	None	Acid	None	None
Second determination (1 gm. soil)						
Peat	None	Room	2,000,000	None		
	10	46	800,000			
	10	50	350,000			
Brown silt loam	None	Room	None	Acid		
	10	46	None			
	10	50	None			

Experiment 17—The effect of calcium carbonate when present in soil upon the thermal death point of nodule bacteria

This experiment was conducted with the view of obtaining definite data with regard to soil acidity as affecting the thermal death point of nodule bacteria.

Acid brown silt loam soil was used. To 2000 gm. of soil, 2 gm. of potassium phosphate was added and then thoroughly mixed. This amount was divided into two equal portions to one of which 1 gm. of calcium carbonate was added and thoroughly mixed. Each lot of soil was inoculated with one-half bottle

infusions each of pea, cowpea, soybean, and sweet clover bacteria. After inoculation, the soil was put aside and 9 days later the thermal death point was determined. This soil was then used for inoculation on the basis of 1 gm. of soil to 14 gm. of seed. It was stored in bags and kept in the laboratory, and after 5 months it was used for inoculation without being heated.

In all cases, abundant nodule production was obtained from inoculated soil with carbonate heated to 40°C., and 50°C. for 10 minutes, but no nodules were produced from soil with potassium phosphate and no carbonate. Even with the unlimed inoculated soil which was not subjected to heat, nodules were not

TABLE 9

The effect of calcium carbonate in soil upon the thermal death point of nodule bacteria

Heated soil used for inoculation

TREATMENTS	ORGANISMS	TIME	TEMPERATURE	NUMBER OF PLANTS	PLANTS WITH NODULES	NUMBER OF NODULES
		minutes	°C.			
Lime + inoculated soil.......	Garden pea	None	Room	7	7	Many
Lime + inoculated soil.......	Garden pea	10	40	6	6	Several
Lime + inoculated soil........	Garden pea	10	50	6	6	Several
Inoculated soil................	Garden pea	None	Room	6	None	None
Inoculated soil................	Garden pea	10	50	6	None	None
Lime + inoculated soil........	Cowpea	None	Room	5	5	Several
Lime + inoculated soil........	Cowpea	10	40	3	3	Several
Inoculated soil................	Cowpea	None	Room	2	None	None
Inoculated soil................	Cowpea	10	40	4	1	1 nodule
Lime + inoculated soil........	Soybean	None	Room	6	2	Several
Lime + inoculated soil........	Soybean	10	40	4	4	Several
Lime + inoculated soil........	Soybean	10	50	6	6	Several
Inoculated soil...............	Soybean	None	Room	6	2	2 nodules
Inoculated soil................	Soybean	10	40	6	2	2 nodules
Lime + inoculated soil........	Sweet clover	10	40	6	6	Many
Lime + inoculated soil........	Sweet clover	10	50	6	6	Many
Inoculated soil................	Sweet clover...	10	40	6	None	None

found on any plant inoculated, with the exception of cowpea and soybean organisms where one and two nodules were found on each plant. This explains the acid resistance of these two organisms.

The 5-months inoculation test, with treated soil not heated, gave the same result as indicated above.

Experiment 18—The effect of soil acidity upon the infecting power of B. radicicola of garden pea

The first part of this experiment was to determine the effect of acid soil upon nodule production, and the second part was to determine the effect of

neutralizing soil acidity upon the nodule production. Three conditions were established as follows: (*a*) A bacterial infusion of *B. radicicola* of garden pea was applied directly to an acid soil, mixed thoroughly and set aside. The next day the non-inoculated seeds were planted in it. (*b*) A non-acid soil was inoculated with bacterial infusion of *B. radicicola* of garden pea, and applied the next day to an acid soil on the basis of 400 pounds of inoculated soil for each acre. Non-inoculated seeds were planted the next day. (*c*) Sterile seeds were inoculated with the bacterial infusion of *B. radicicola* of garden pea, and the next day these inoculated seeds were planted in an acid soil.

In the second part, the soils were treated with calcium carbonate until the acidity was completely neutralized; no definite amount of carbonate was used. These neutralized soils were moistened to about 25 to 30 per cent moisture and then thoroughly mixed. After 2 days storage, during which the moisture content was not materially reduced, they were used as described under the first part.

The soils used were gray silt loam on tight clay, for the first part, gray silt loam on tight clay and brown silt loam for the second part. Both soils were acid although the brown silt loam was not so acid as the gray.

In order to test the infecting power of the organisms used, inoculated seeds were planted in sterile sand under controlled conditions.

In all cases, pint jars were used, each containing 5 seeds, and the plants were allowed to grow for 25 days before nodule examinations were made.

In the first part nodules were absent on all the plants. Not one of the 38 plants grown showed normal growth and gradually died after 20 days. They were washed for nodule examination, however, before they died. The 6 plants in the second part of the experiment that were inoculated from the same bacterial infusion, and then planted in sterile sand, had plenty of nodules, indicating that the infusion used was a nodule producer. The result of the second part showed that under all conditions, all plants in the treated brown silt loam possessed nodules, whereas the plants in the treated gray silt loam on tight clay produced no nodules. The plants in the brown silt loam also looked healthier.

PART V—THE LIFE CYCLE OF VARIOUS NODULE BACTERIA AS INFLUENCED BY CALCIUM CARBONATE, CALCIUM PHOSPHATE, CERTAIN CHLORIDES AND ACIDS

The purpose of this study was to determine the influence of various chemicals on the forms of nodule bacteria, and to determine whether the chemicals used tend to encourage or to inhibit the development of the infective form of the organisms.

Some suggestive work has already been conducted by Bewley and Hutchinson, Löhnis, Löhnis and Smith, Burrill and Hansen, and Whiting and Hansen on stages in the life cycle of nodule bacteria.

This study is concerned with the influence of calcium carbonate and calcium phosphate on the forms of the organisms. In acid soils the organism comes into direct contact with the acid salts. The second part of this work is so planned as to study whether it is the true acidity, the total acidity, the toxic effect of the salts applied, or the absence of calcium in the form of the carbonate and bicarbonate that is most injurious to the growth of the organisms.

Methods employed

The nodule bacteria used were garden pea, red clover, and soybean. These cultures were kept pure during the progress of the work.

Mannite media was used in all experiments. In all the media prepared, excepting the normal one, carbonate was entirely eliminated; however, calcium was supplied in the form of calcium sulfate. Twenty-five cubic centimeters of the prepared media was placed in each of the 50-cc. Erlenmeyer flasks, and the particular element or compound to be added was computed on that volume in per cent for bases and pH values for acids. The acid was sterilized and added to the sterile media. The calcium carbonate and tricalcium phosphate were added to the media before sterilization. In order to obtain an even distribution of the chemical added, the media were constantly shaken while solidifying. One loopful of bacterial infusion was transferred to each flask and then incubated at 26° to 28°C. At frequent intervals microscopic examinations were made from which detailed drawings of many individual organisms are shown in plate 1.

Considerable difficulty was experienced in preparing the slides for staining. The best procedure found was as follows: A sample from the margin of growth was obtained with the point of a platinum needle. This sample was diluted three times with a drop of sterile water at each dilution, being constantly mixed during the process. After a third dilution, the slime had been satisfactorily separated and a loopful of this diluted sample was spread very thinly on the slide and allowed to dry without the application of any artificial heat, after which, carbol-fuchsin stain of very weak dilution (5 cc. of saturated alcoholic fuchsin solution to 45 cc. of 5 per cent carbolic acid solution) was applied and allowed to remain for one minute. Other stains were tried but unsatisfactory results were obtained. To overcome the difficulty with slime, different organic and inorganic solvents, such as dilute alcohol, ether, acids, and physiological salt solutions, were tried but were found ineffective. The stain was then washed in the usual manner. Micro-photographs and drawings were made of representative stains.

Experiment 19—The effect of calcium carbonate

The organisms were grown in media free from carbonate and also in media containing 0.5 per cent of calcium carbonate. It was observed that garden pea and red clover organisms showed a vigorous growth in carbonated media, but a poor growth in non-carbonated media where they died within a month.

Soybean organisms grew equally well in both media for about a month, then the organisms in the non-carbonated media stopped growing and finally died out.

Microscopic examination showed that garden pea organisms grown in non-carbonated media were large, rod-shaped, possessed of a thick cell wall, and contained two or more very defined bands. The average size was 4.03μ long and 1.20μ wide, and the longest observed was 5.64μ long. Those organisms grown in carbonated media were very small and irregular in shape, the cell wall was very thin, single polar individuals predominated, and the whole body did not stain freely. Branched forms were noticed. The average size was 1.6μ long and 0.8μ wide.

Red clover bacteria grown in non-carbonated media exhibited the same form and characteristics as those of garden pea grown in the same kind of media, with the exception that banded individuals were not found among the red clover organisms, but instead granules throughout the body were observed. The average size was 4.03μ long and 1.2μ wide. The longest observed was 6.44μ and the shortest was 1.61μ. In the carbonated media, the organisms were very small, irregular in shape, highly vacuolated, with a branched form predominating. Polar and granulated bodies were also present, and extremely thin cell wall was observed without exception.

In non-carbonated media, the soybean bacteria were small rods staining polar. The average size was 2.41μ long and 0.4μ wide and the longest was 4.8μ. The organisms grown in carbonated media usually possessed three segments, but it was not uncommon to find five or six segments.

Two forms were observed regularly, one with a small round or oblong body half of which was heavily stained, and the other, long and segmented. The average size of the individuals belonging to the first form was 0.4 to 0.5μ long and 0.3μ wide, and for the other was 5μ long and 0.3μ wide. The longest was 8μ and the shortest was 3.4μ.

When these three kinds of nodule bacteria were grown reciprocally, that is, the organisms in carbonated media were transferred to the non-carbonated and those from the non-carbonated were transferred to carbonated, their form changed in accordance with the description above.

Experiment 20—The effect of tricalcium and acid phosphates

In this experiment, the amount of tricalcium phosphate was the same as that of carbonate. But the amount of acid phosphate applied was computed so as to have an initial acidity of pH 5.2 with 25 cc. media used. This pH was established for all organisms concerned in this experiment.

It was found that garden pea and red clover organisms grown in non-phosphated media were large and very much like those grown in non-carbonated media. Soybean bacteria in non-phosphated media were extremely long but showed no change in diameter. The average size was 6.4μ long and 0.4μ wide. The longest were 10μ and mostly single polar organisms, but twos

were occasionally found. The tricalcium and acid phosphate had approximately the same effect upon the form of garden pea and red clover. Tricalcium media had a tendency to produce a branched form, although with both media the formation of round bodies resulted among garden pea and red clover bacteria. These forms may seem to resemble the shape of the first and second stages proposed by Bewley and Hutchinson. With soybean organisms, the acid phosphate media encouraged the formation of long segmented rods and a few oblong organisms. The tricalcium phosphate brought about the formation among the soybeans of oblong bodies very much enlarged at the poles, constituting over a half of the entire body. Long rods were not found in this experiment.

Experiment 21—The effect of aluminum chloride, and hydrochloric, acetic, nitric, and sulfuric acids

The media were acidified by the different acids mentioned and different pH values were established for each kind of organism; pH 5.2 for garden pea and red clover bacteria, and pH 4.5 for soybean bacteria. The pH values were adjusted colorimetrically.

The results showed that aluminum chloride and hydrochloric acid had a similar effect upon the form of garden pea, red clover, and soybean bacteria. The garden pea organisms were club-shaped with very well defined and heavy banding; the red clover were irregular rod-shaped with thin cell walls, but inclosed in each was a mass of more condensed matter running lengthwise from end to end. Soybean organisms were long and segmented.

Acetic acid had a very striking effect upon the form of nodule bacteria, especially of garden peas and red clover. The organisms were flat with very thin cell walls, and with two or three branches. Three-cornered individuals had three poles; four-cornered individuals had four poles, etc. The width was almost the same as the length. This shape was found commonly. The soybean bacteria here were also long segmented rods with sometimes a branched form. The longest observed was 16μ.

The effect of nitric and sulfuric acids upon the form of garden pea and red clover bacteria was the same as that of aluminum chloride and hydrochloric acid. Segmentation was not very common among the soybean organisms. It was found that the bodies were banded with thread-like substances, interwoven with dots. In general, the organisms were large in case of garden pea and red clover, and were long in case of soybean.

SUMMARY

It was found that the rate of multiplication was greater in high dilution than in low dilution, that is, more bacteria were produced in the gallon dilution than in the pint dilution. It was also noticed that *B. radicicola* of garden pea lived long in solution (142 days).

Oxygen was a limiting factor during the growth of nodule bacteria in solu-

tion. Shaking the bottles or containers in which the organisms were growing helped to introduce some oxygen and gave increased growth.

Calcium carbonate added in media, stimulated growth of *B. radicicola* better than tricalcium phosphate.

The heat resistance of *B. radicicola* of garden pea and sweet clover, and *Ps. radicicola* of cowpea and soybean was lower than the heat resistance of *B. radiobacter* and *Azotobater chroococcum.* The legume organisms were killed at 50°C. for 10 minutes exposure, whereas *B. radiobacter* and *Azotobacter chroococcum* were alive at 50°C. for 10 minutes exposure.

The solution in which the organisms were suspended had an influence on the heat penetration: the denser the solution, the slower the heat penetrated, and the thinner the solution, the faster the heat penetrated.

Peat maintained the life of nodule bacteria at a much higher temperature than brown silt loam. Acid soil decreased the thermal death point of legume organisms, and the organisms died in such soil after a short period of storage. The addition of calcium carbonate increased the thermal death point and the keeping quality of legume organisms.

Abnormal media encouraged changes in the forms of nodule bacteria. The normal bacteria were smaller than the bacteroids.

The absence of phosphate or carbonate in the media resulted in the formation of bacteroids. The presence of tricalcium or acid phosphate in the noncarbonated media, did not stimulate the production of active forms.

Aluminum chloride and hydrochloric acid had like effects on the form of legume bacteria.

The presence of acetic, nitric, and sulfuric acids in media changed the legume bacteria into bacteroids and each of these acids affected the form of the organisms specifically.

REFERENCE

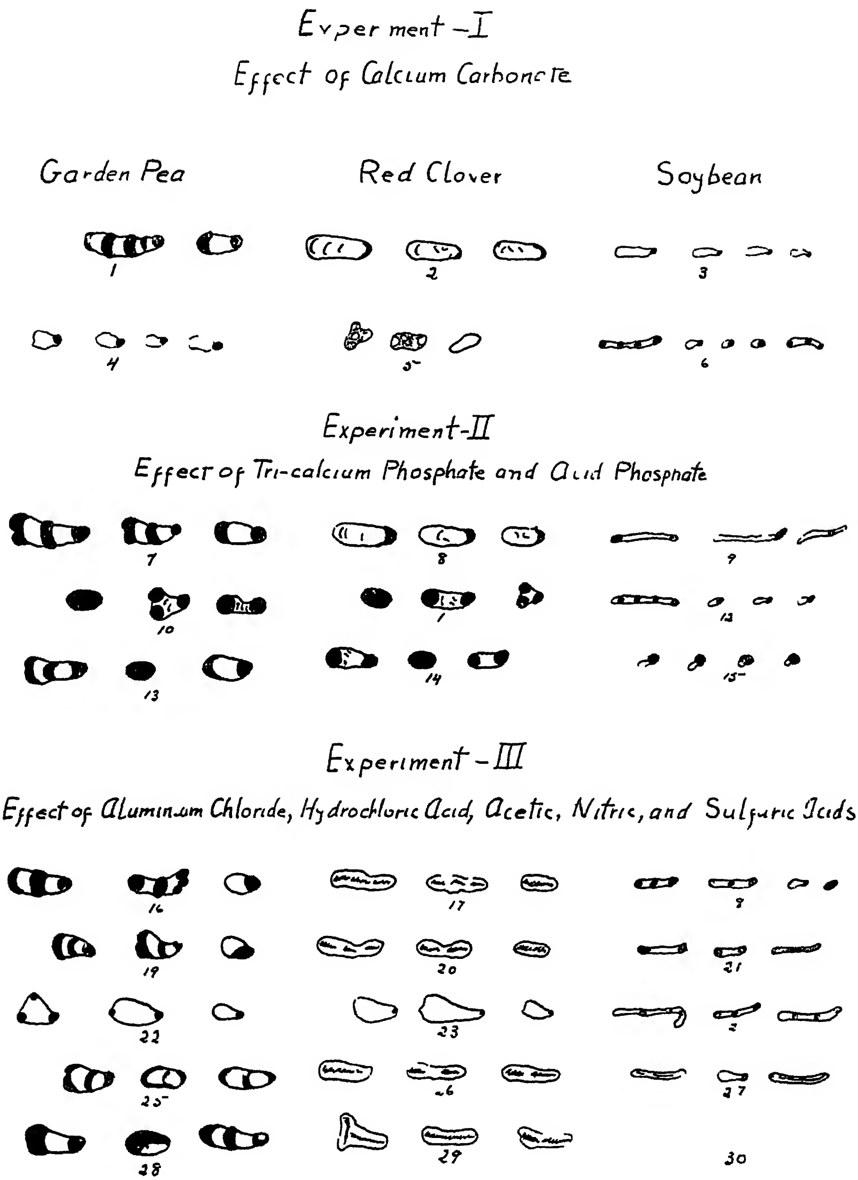
(1) Löhnis, F., and Hansen, R. 1921 Nodule bacteria on leguminous plants. *In* Jour. Agr. Res., v. 20, p. 543.

(2) Zipfel, H. 1912 Beiträge zur Morphologie und Biologia der Knollchenbakterien der Leguminosen. *In* Centbl. Bakt. (etc.), v. 32, p. 97–137.

PLATE I

Enlarged from actual size. Magnification $\times$ 950. (Carbol-fuchsin stain.)

FIGS. 1, 2 AND 3. Grown in media without calcium carbonate.
FIGS. 4, 5 AND 6. Grown in media with calcium carbonate.
FIGS. 7, 8 AND 9. Grown in media without phosphorus.
FIGS. 10, 11 AND 12. Grown in media with acid phosphate.
FIGS. 13, 14 AND 15. Grown in media with tricalcium phosphate.
FIGS. 16, 17 AND 18. Grown in media with aluminum chloride.
FIGS. 19, 20 AND 21. Grown in media with hydrochloric acid.
FIGS. 22, 23 AND 24. Grown in media with acetic acid.
FIGS. 25, 26 AND 27. Grown in media with nitric acid.
FIGS. 28, 29 AND 30. Grown in media with sulfuric acid.


Experiment-I
Effect of Calcium Carbonate
Garden Pea
Red Clover
Soybean
1
2
3
4
5
6
Experiment-II
Effect of Tri-calcium Phosphate and Acid Phosphate
7
8
9
10
11
12
13
14
15
Experiment-III
Effect of Aluminum Chloride, Hydrochloric Acid, Acetic, Nitric, and Sulfuric Acids
16
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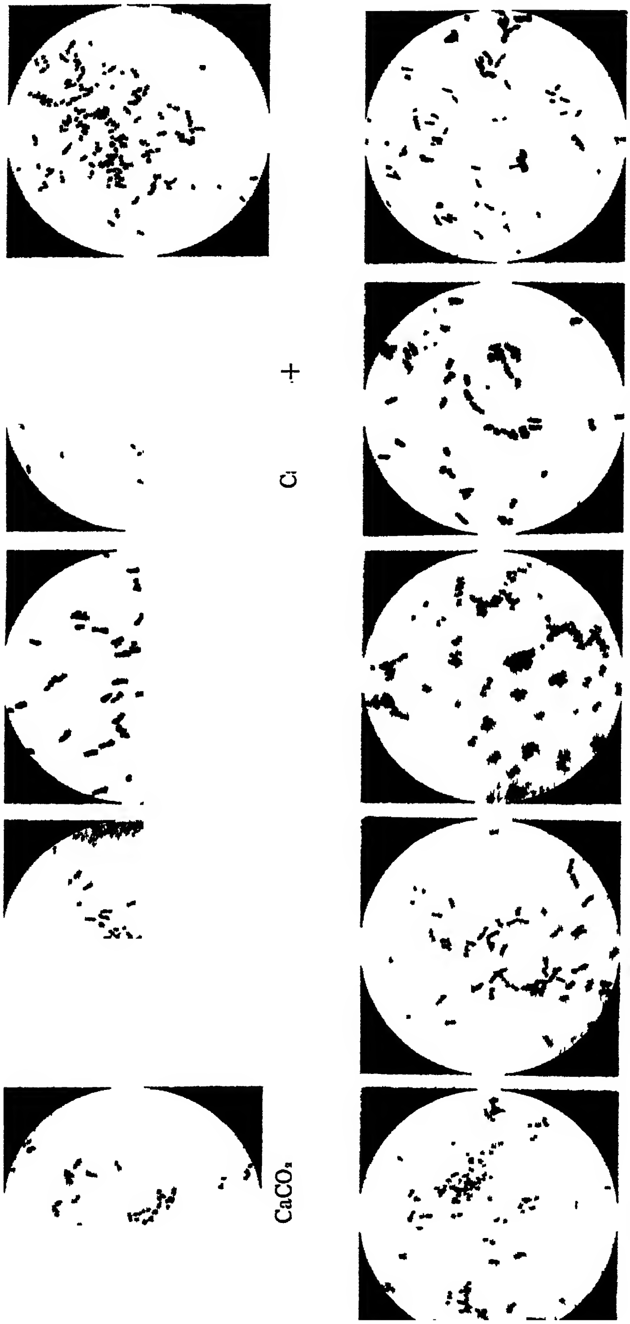
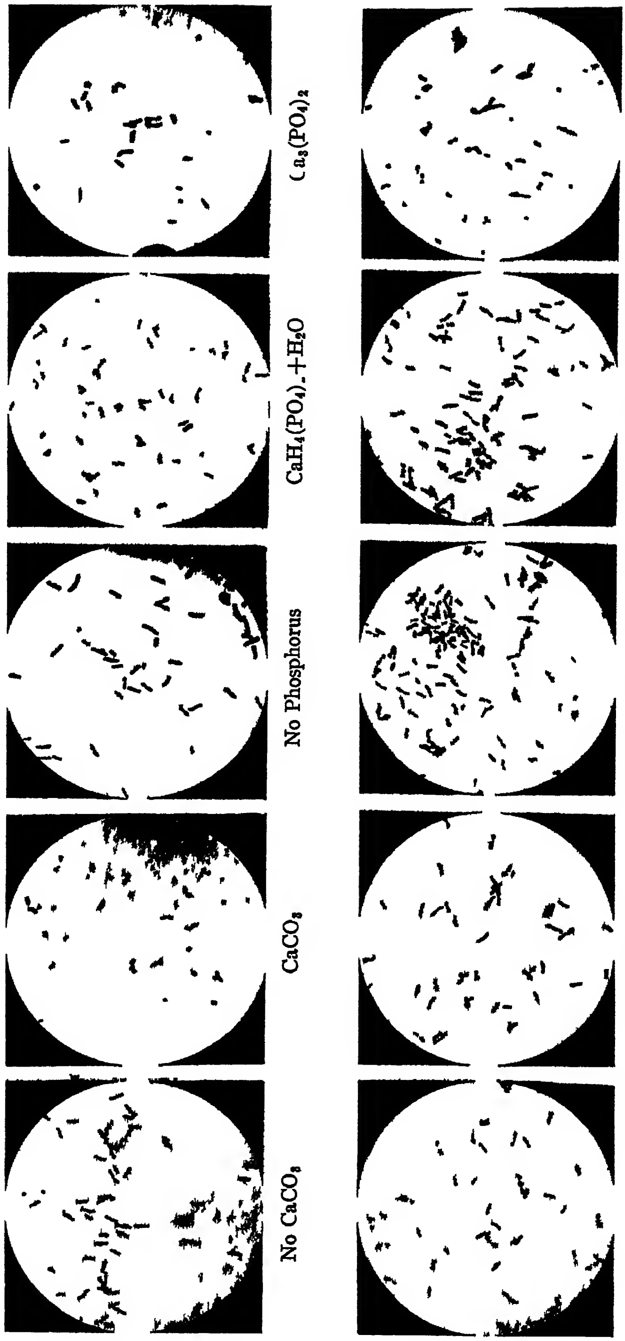


PLATE 2
GARDEN PEA
Stained with carbol-fuchsin. Magnification × 950



No $CaCO_3$ — $CaCO_3$ — No Phosphorus — $CaH_4(PO_4)_2+H_2O$ — $Ca_3(PO_4)_2$

HCl — Al_2Cl_6 — HNO_3 — H_2SO_4 — $C_2H_4O_2$

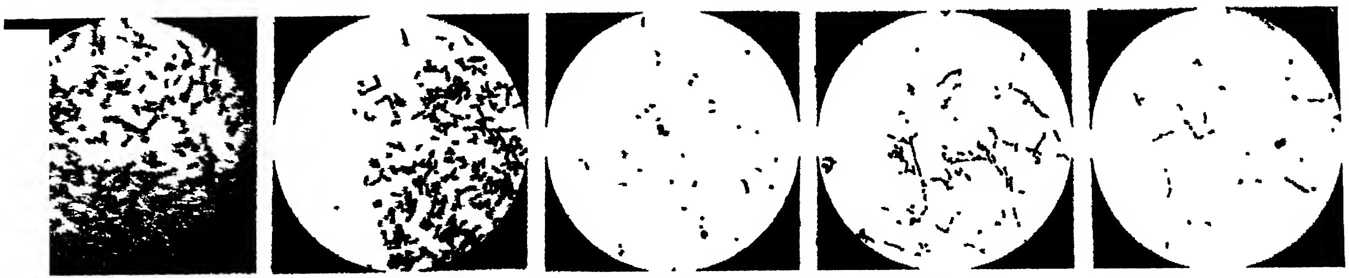
PLATE 3

RED CLOVER

Stained with carbol fuchsin. Magnification × 950

PLATE 4
SOYBEAN
Stained with carbol-fuchsin. Magnification × 950

No $CaCO_3$ | $CaCO_3$ | No Phosphorus | $Ca\ H_4(PO_4)_2 + H_2O$ | $Ca_3(PO_4)_2$



HCl | Al_2Cl_6 | HNO_3 | H_2SO_4 | $C_2H_4O_2$

THE INFLUENCE OF AVAILABLE NITROGEN ON THE FERMENTATION OF CELLULOSE IN THE SOIL[1]

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PART I

Introduction

The presence of nitrogenous compounds which can be utilized by plants usually determines more than any other factor the success of a crop. Any conditions, therefore, which deal with available nitrogenous compounds and the processes by which they are produced or rendered unavailable are of great practical importance. That the addition of organic material of high carbohydrate content, such as plant residues, to soils is accompanied by a reduction of the available soil nitrogen—nitrates in particular—has been known since the days of Mulder (12). Various circumstances surrounding this loss of nitrates and the process of nitrate formation have long been subjects of research, but until a suitable method for determining cellulose in soils was developed it was quite impossible to determine in a quantitative way the influence of nitrogen on the cellulose, or carbohydrate, decomposition, as only the nitrogen could be determined, which gave us but a partial insight into the biological processes concerned. It is thought that the experiments herein described will be an aid to the understanding of the interrelation between the two processes of carbohydrate decomposition and of nitrate formation.

A review of the literature dealing with the influence of organic compounds on the loss of nitrates in the soil is unnecessary here. It is desirable, however, to summarize the chief deductions from certain researches that are intimately connected with the results obtained from the experiments described in this paper.

In a paper published in 1920 Charpentier (4) described a method for the quantitative determination of cellulose in soils, and in a later paper (5) called attention to the increased rate of cellulose decomposition where manure had been added to the soil. Barthel and Bengtsson

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[1] This paper has been published in Swedish as a bulletin from the Central Swedish Agricultural Experiment Station, but because of the inaccessibility of the original to most of the workers in English speaking countries, its English translation is presented in Soil Science.

[2] The author wishes to thank Professor Chr. Barthel and Assistants Bengtsson, Sandberg, and Bjälfve for their splendid coöperation and kindness during the period he studied as a Fellow in the former's laboratory.

(2) improved on the method which Charpentier had worked out in the former's laboratory. They studied the influence of ammonium salts, of nitrates, and of stable manure on the course of the cellulose fermentation and showed that the increased rate of fermentation which Charpentier had observed was due to the available nitrogen present in the manure, and not to the bacteria, as sterilized and unsterilized manures of like ammonia content were equally efficient in bringing about this decomposition. In papers published subsequent to the commencement of the experiments herein described, Fred and Viljoen (8), Söderbaum and Barthel (13), Waksman and Heukelekian (15), and Waksman and Starkey (16) have also drawn attention to certain relations existing between the presence of cellulose in the soil and its fertility as influenced by its available nitrogen content. Fred and Viljoen by nitrification and pot experiments studied the cause of poor crop yields on newly cleared land where much undergrowth had been plowed under in the clearing process. They came to the conclusion that the poor yields were caused by a lack of nitrates in the soil due to the cellulose decomposition, and not to toxic materials in the plants plowed under. Söderbaum and Barthel in a series of nitrification and pot experiments with oats showed that the addition of sawdust to soil caused a loss of nitrates during the cellulose fermentation and a corresponding inhibition of vegetation. These conditions continued until the cellulose was destroyed and nitrates were again available for the plants. They found that by the addition of sufficient amounts of sodium nitrate to soil containing sawdust the injurious effects accompanying the cellulose fermentation could be overcome. Waksman and Heukelekian studied the rate of cellulose decomposition in different soils with and without the addition of nitrate nitrogen and determined the number of fungi, bacteria, and actinomycetes present. They found that the number of organisms increased very greatly during the cellulose fermentation, and concluded that the decomposition of cellulose can be added to the group of methods used for carrying out a microbiological analysis of a soil. Waksman and Starkey determined the effect of various organic materials on the numbers of microörganisms in the soil. They found that dextrose, cellulose, rye straw, alfalfa meal, and dried blood greatly increased the number of microorganisms, but that certain substances favored the increase in number of a certain group, or groups, of microörganisms and that other substances increased the number in all groups.

Methods

In these experiments 1 or 1½ per cent of cellulose in the form of very finely divided Munktell filter paper number 10 was added to 200 gm. of heavy clay loam soil. After a thorough mixing the soil was placed in wide-mouthed glass bottles. The various amounts of nitrogen employed were added in the form of an ammonium sulfate or sodium nitrate solution, the same solution being used in experiments 1 and 2. Water was then added to bring the moisture content to its optimum, or 18 per cent. The flasks, after a thorough mixing, which was deferred until the following day for the purpose of obtaining a good soil structure, were stoppered with paraffined cork stoppers provided with short glass tubes containing cotton plugs. The latter permitted a certain amount of aeration with very little change of moisture content. After the desired period of incubation at 18°C., analyses were made for cellulose, for nitrates, and in some instances, for ammonia.

The cellulose determinations were made according to the method worked out in this laboratory by Charpentier and subsequently modified somewhat by Barthel and Bengtsson (2).

The nitrate determinations were made by the usual phenol disulfonic acid method.

Ammonia was determined in experiment 2 by extracting it from the soil with the aid of a potassium chloride solution, as suggested by Bengtsson (3) and Harper (10). The solution was then made alkaline and the ammonia distilled into tenth normal sulfuric acid and determined by Nesslerization, a colorimeter as recommended by Folin (6, 7), being used.

All values, with the exception of a few nitrate and ammonia values, are the average of two closely agreeing analyses, the two results being from different bottles containing soils that received the same treatment, and are not duplicate analyses of the contents of one bottle.

TABLE 1

The rate of cellulose fermentation and accompanying denitrification in the presence of increasing amounts of nitrogen

SAMPLE	NITROGEN ADDED	CELLULOSE FERMENTED IN			NITRATE NITROGEN*			AMMONIA* 42 days	REACTION 42 days
		17 days	24 days	42 days	Start	24 days	42 days		
	mgm.	*per cent*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*pH*
Check	0	20.7	20.3	18.7	8.6	0	0	0	7.4
1	3.9	41.0	42.0	45.9	8.6	0	0	0	7.1
2	7.8	54.0	59.6	63.1	8.6	0	0	0	6.8
3	11.7	63.0	70.5	81.3	8.6	0	0	0	6.4
4	15.6	68.1	83.9	87.0	8.6	0	Trace	0	6.3
5	19.5	71.4	84.0	90.0	8.6	0	8.3	Trace	6.3
6	23.4	76.2	91.3	92.9	8.6	8.4	23.0	+	6.2
7	27.3	74.2	84.5	92.9	8.6	17.3	41.1	++	6.2
8	31.2	70.1	87.9	92.4	8.6	18.6	96.4	+++	6.1
9	35.1	73.7	87.7	96.8	8.6	21.9	105.0	++++	6.0
10	39.0	74.3	85.3	92.5	8.6	23.0	95.2	+++++	6.0

* per kgm. dry soil.

Experimental

In experiment 1 ammonium sulfate was added to 200 gm. of soil in quantities increasing from one to ten times the amount of ammonia added in a 2 per cent application of stable manure. The ammonia nitrogen present in a certain well decomposed manure was found to be 0.194 per cent. This value was used in calculating the quantities of ammonium sulfate to be added. The control bottles contained the same amounts of soil, cellulose, and moisture, but received no ammonium sulfate, the only nitrogen present being that in the original soil. Analyses for cellulose were made after the bottles had been standing 17, 24, and 42 days at 18°C. Nitrates were determined after 24 and 42 days. The results are shown in table 1, in which the cellulose fermented is given in per cent of the cellulose added. The data are expressed graphically in figure 1, the lower curve indicating the ratio between nitrogen and cellulose fermented after 24 days.

After the first analyses had been made in experiment 1 it was noted that the

sulfuric acid formed by the removal of ammonia from the ammonium sulfate was sufficient to alter considerably the reactions of the soils in the various bottles. Since the fermentation of cellulose is a process which may be participated in by different groups of organisms, such as bacteria, actinomycetes, and molds, it was desired that all soils should be at the same hydrogen-ion concentration so that the fermentations in the different bottles would be brought about by the same groups of organisms. In experiment 1 it was noted that the mold growth increased with increasing amounts of ammonium sulfate and with the accompanying increase of acidity. Experiment 2 was therefore

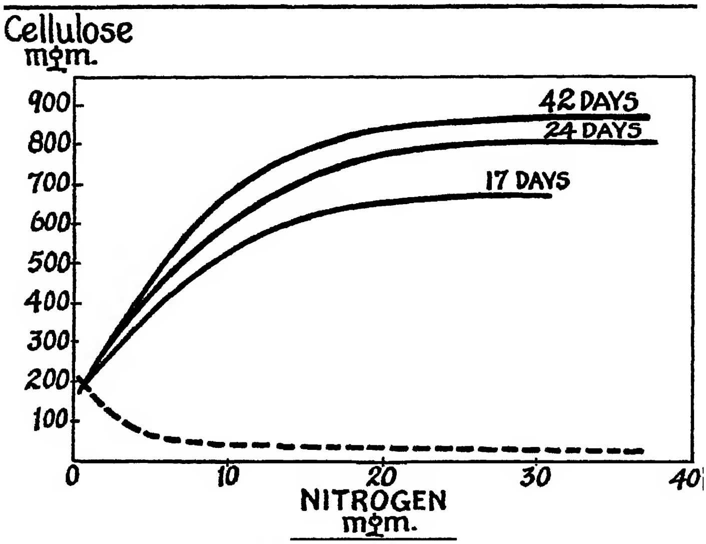

FIG. 1. THE RATE OF CELLULOSE FERMENTATION IN THE PRESENCE OF INCREASING AMOUNTS OF NITROGEN

The three upper curves indicate the amounts of cellulose fermented at various nitrogen after 17, 24, and 42 days respectively. The lower curve shows the ratio of nitrogen to cellulose fermented after 24 days.

conducted with conditions much the same as in experiment 1, but instead of 200 gm. of soil, 198 gm. of soil and 2 gm. of calcium carbonate were used, the latter maintaining a constant reaction of pH 7.3. The amount of cellulose was increased to 1½ per cent. The results of experiment 2 are given in table 2 and are shown graphically in figure 2. In this experiment as in the previous one, the mold content increased with increasing amounts of ammonium sulfate, as might be expected, although the reaction remained constant.

The results of these two experiments indicate that the fermentation of cellulose proceeds with great rapidity in the presence of ammonia or of nitrate nitrogen, the rate of decomposition being dependent upon the relative concentrations of nitrogen and cellulose. The amount of cellulose decomposed per milligram of nitrogen is not constant but varies inversely with the available

nitrogen present in the soil. The ratios of nitrogen utilized to cellulose fermented, as found in the experiments herein described, are given in table 3,

TABLE 2

*The rate of cellulose fermentation and accompanying denitrification in the presence of increasing amounts of nitrogen**

SAMPLE	NITROGEN ADDED	CELLULOSE FERMENTED IN			NITRATE NITROGEN†					AMMONIA NITROGEN†	
		10 days	30 days	60 days	Start	10 days	30 days	50 days	60 days	10 days	30 days
	mgm.	*per cent*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
Control	0	14.6	18.8	22.3	13.8	0	0	0	0		12.3
1	3.9	23.7	37.4	52.0	13.8	0	0	0	0	9.9	....
2	7.8	30.9	49.5	65.0	13.8	0	0	0	0	10.7	13.3
3	11.7	37.7	57.3	74.8	13.8	0	0	0	0	12.5	....
4	15.6	35.9	65.9	87.5	13.8	Trace	0	0	0	15.2	21.8
5	19.5	33.1	64.4	88.7	13.8	8.5	0	0	0	14.2	11.9
6	23.4	34.9	78.5	92.7	13.8	15.3	0	0	Trace	16.0	12.9
7	27.3	33.5	75.9	94.7	13.8	21.2	0	0	8.4	19.6	18.2
8	31.2	32.8	78.2	95.6	13.8	23.4	1.4	13.3	37.8	19.9	21.6
9	35.1	36.3	81.2	96.7	13.8	19.9	8.8	53.6	71.1	33.4	29.7
10	39.0	39.0	83.9	96.6	13.8	14.8	9.9	90.7	115.6	37.9	34.2

*pH=7.3.
†per kgm. dry soil.

TABLE 3

Ratios of nitrogen utilized to cellulose fermented

SAMPLE NUMBER	NITROGEN ADDED	EXPERIMENT 1			EXPERIMENT 2			EXPERIMENT 3	
								After 14 days	
		17 days	24 days	42 days	10 days	30 days	60 days	Ammonia nitrogen	Nitrate nitrogen
	mgm.								
Control	0*	1:222	1:218	1:200	1:145	1:241	1:223	1:72	1:72
1	3.9	1:79	1:81	1:84	1:62	1:98	1:136		
2	7.8	1:58	1:64	1:63	1:47	1:75	1:98		
3	11.7	1:46	1:52	1:60	1:40	1:61	1:79		
4	15.6	1:38	1:50	1:49	1:29	1:54	1:74		
5	19.5	1:32	1:38	1:46	1:23	1:43	1:59	1:14	1:22
6	23.4	1:29	1:34	1:37		1:44	1:52		
7	27.3	1:23	1:30	1:33		1:37			
8	31.2		1:27	1:28		1:30			
9	35.1		1:24	1:26		1:31			
10	39.0		1:22	1:23		1:29			

*The soil used for experiment 1 contained 0.86 mgm.; for experiment 2—1.38 mgm.; and for experiment 3—0.35 mgm. nitrate nitrogen per 100 gm. dry soil.

and are shown graphically in the lower curves of figures 1 and 2. From these it is seen that when the amounts of available nitrogen are very small the ratios of nitrogen utilized to cellulose fermented may be very low, as is indicated by

the control bottles where the only nitrogen present is for the most part in the form of nitrates in the original soil. In experiment 1 where 0.86 mgm. of nitrate nitrogen were present for each hundred grams of soil in the control bottles, 188 and 186 mgm. of cellulose were fermented within 24 days, with corresponding ratios of nitrogen to cellulose of 1:219 and 1:216 respectively. These ratios, however, may not be exactly comparable to those from the soils receiving ammonia nitrogen, for the ratio of nitrogen utilized to cellulose fermented appears to be somewhat higher with nitrate nitrogen than with am-

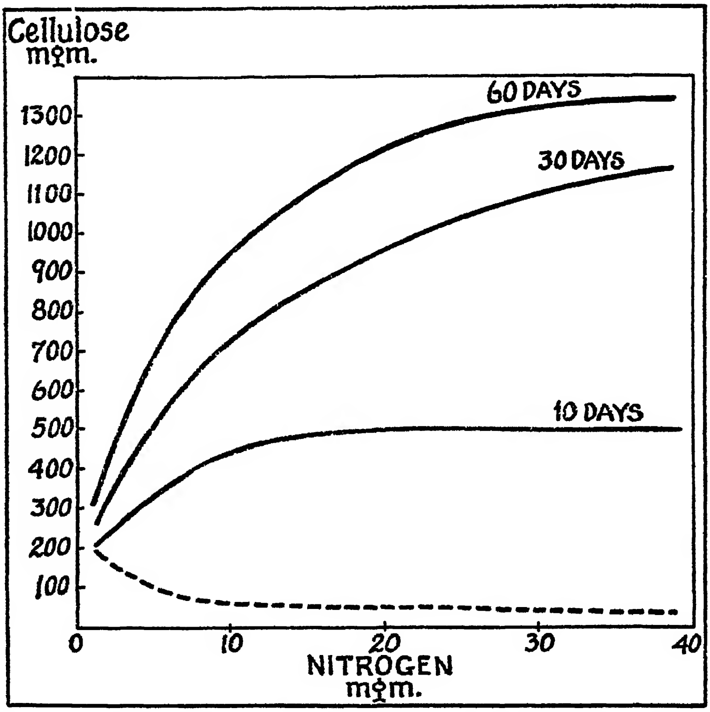

FIG. 2. THE RATE OF CELLULOSE FERMENTATION IN THE PRESENCE OF INCREASING AMOUNTS OF NITROGEN

The three upper curves indicate the amounts of cellulose fermented at various nitrogen concentrations after 10, 30, and 60 days. The lower curve shows the ratio of nitrogen utilized to cellulose fermented after 30 days.

monia nitrogen, as is shown in experiment 3. With increases in the amounts of nitrogen this ratio increased until it reached a value of 1:22 in the soils receiving ten times the amount of ammonia present in a 2 per cent application of manure. Although it is doubtless true that available nitrogen was formed by ammonification and nitrification of the original constitutent of the soil, this amount is almost negligible when compared with the amounts of nitrogen added to the soils, for under conditions similar to these experiments only 14.8 to 15.1 mgm. of nitrate nitrogen was formed per kilogram of dry soil during

three months, or 0.5 mgm. per 100 gm. of soil during each month. This data therefore fails to support the general statement of Waksman and Heukelekian (15, 14) that "for every milligram of nitrogen that is available in the soil or that can become available in a given period, 40 to 50 mgm. of cellulose will be decomposed." This conclusion was doubtless correct for the specific conditions of their experiments.

That nitrification can occur in the presence of appreciable amounts of cellulose is concluded from these results, for in both experiments an accumulation of nitrates occurred when the ratio of nitrogen to cellulose was approximately 1:35. Figure 3 shows graphically the cellulose fermented and the nitrates present from time to time in soil 8, experiment 1, and soil 10, experiment 2. The data of experiment 1 show clearly that nitrates accumulated from the very start of the experiment in those soils which received the largest amounts of ammonia. Where less ammonia was added, all available nitrogen was utilized by the organisms that fermented the cellulose. Under such conditions nitrates could not accumulate. The results of experiment 2 demonstrate this even better, for a more careful study of the nitrification process was made in this experiment. The data do not coincide exactly with those of the former experiment because only 1 per cent of cellulose was used in experiment 1 whereas 1½ per cent was used in experiment 2. It seems clear, therefore, that nitrification occurs in the soil in the presence of cellulose, but that unless the available nitrogen is in excess of that required by the organisms which develop on the cellulose for their nitrogen metabolism, the nitrates will be utilized by the cellulose fermenters as rapidly as they are formed by the nitrate-forming organisms. This is contrary to the opinion expressed by van Iterson (11) and more recently by Gibbs and Werkman (9), that the cellulose inhibits nitrification.

The presence of ammonia is taken to indicate that ammonification can proceed in the presence of considerable amounts of cellulose and that it is not quite so readily utilized by cellulose fermenters as are nitrates, for ammonia was found when nitrates were not.

Experiment 3 was then conducted to determine whether ammonia could be used as such in the fermentation of cellulose or whether it was converted to nitrates and then utilized. For this purpose the soil was acidified with sulfuric acid to a pH of 4.9, a reaction slightly below that at which nitrification is inhibited in this soil. After the soil had been left standing several days to make sure an equilibrium existed between soil and acid the tests were prepared as follows:

Control bottles:	200 gm. soil, 3 gm. cellulose.
Bottles 1a and 1b:	200 gm. soil, 3 gm. cellulose, 23.4 mgm. nitrogen as ammonium sulfate.
Bottles 2a and 2b:	200 gm. soil, 3 gm. cellulose, 23.4 mgm. nitrogen as sodium nitrate.

All bottles were made up to a moisture content of 18 per cent and incubated at 20°C. Analyses were made after 14 and 98 days. The results of this experiment, which are shown in table 4, indicate that in an acid reaction the fermentation of cellulose proceeds with rapidity in the presence of ammonium

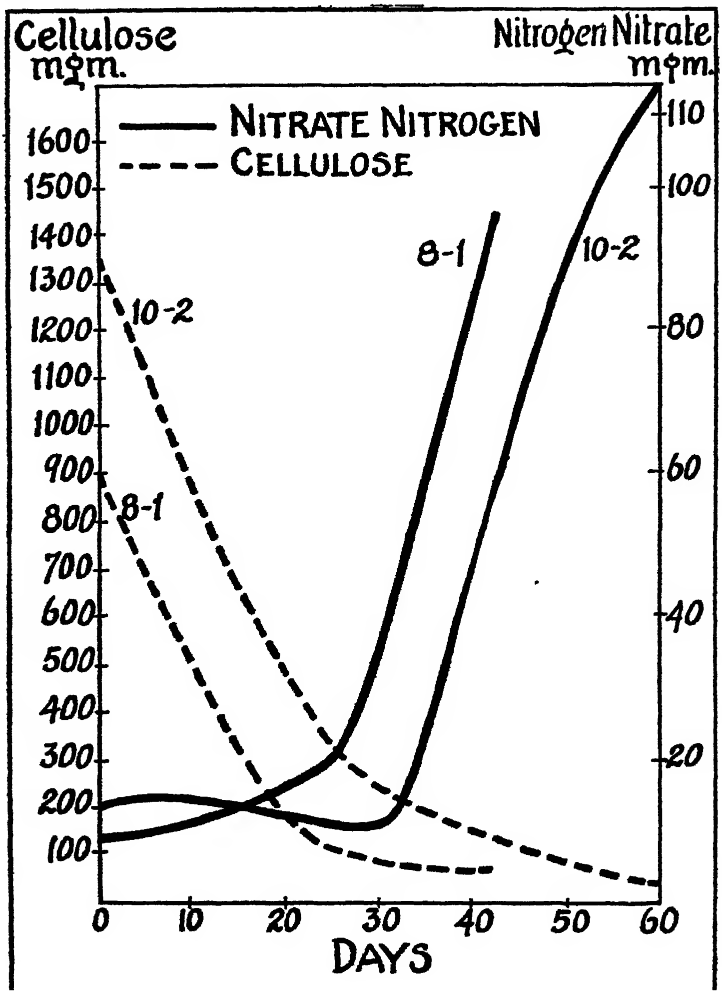

FIG. 3. THE RATES OF CELLULOSE FERMENTATION AND ACCOMPANYING NITRIFICATION

— — — — Cellulose.—8 – 1 = Soil 8, Experiment 1.

———— Nitrate Nitrogen.—10 – 2 = Soil 10, Experiment 2.

nitrogen, and that its conversion to nitrates is not necessary. It is noteworthy that the fermentation proceeded much less rapidly at pH 4.9 than at pH 7.3. The data of experiment 3 and the analyses of the control bottles in experiments 1 and 2 seem to indicate that the presence of nitrate nitrogen accelerates

the cellulose fermentation to a greater extent than does the presence of ammonia. The evidence, however, is rather insufficient to establish such a conclusion as a fact. Ammonia is known to stimulate the development of molds whereas nitrates do not. It may be that in the presence of the nitrates a greater bacterial development occurred of a kind which ferments cellulose more rapidly than do the organisms which were favored by the presence of ammonia. Also, a change of reaction occurred in the two soils as the nitrogen was utilized;

TABLE 4

*The relative availability of ammonia and nitrate nitrogen**

SAMPLE	NITROGEN ADDED		NITRATES AT START	CELLULOSE FERMENTED	
	Form	Amount		14 days	98 days
		mgm.	*mgm.*	*per cent*	*per cent*
Control		0	3.5	11.6	54.0
Control		0	3.5	6.5	
1a	$(NH_4)_2SO_4$	23.4	3.5	23.3	93.4
1b	$(NH_4)_2SO_4$	23.4	3.5	24.0	93.1
2a	$NaNO_3$	23.4	3.5	37.0	100.0
2b	$NaNO_3$	23.4	3.5	38.1	100.0

*pH = 4.9.

TABLE 5

Availability of nitrogenous organic compounds

COMPOUND ADDED TO SOIL	AMMONIA NITROGEN	AMIDE NITROGEN	AMINO NITROGEN	TOTAL NITROGEN	CELLULOSE FERMENTED IN 91 DAYS
$(NH_4)_2SO_4$..........	3.9			3.9	61.9
Urea..............		3.90		3.9	60.2
Aspartic acid........			3.90	3.9	61.2
Asparagin..........		1.95	1.95	3.9	59.8
Alanine............			3.90	3.9	61.3
Tyrosine...........			3.90	3.9	55.8
Peptone............			3.90	20.5	93.4
Casein.............				3.9	65.3
Manure............	3.9			12.2	67.2
Control............				0	25.5
Control............				0	28.5

the soil which received the ammonium sulfate becoming more acid, and that which received the sodium nitrate becoming less acid as the fermentation proceeded.

Nitrification did not occur during the above experiment. A control bottle to which ammonium sulfate but no cellulose had been added, contained at the start 17.6 mgm. of nitrate nitrogen per kilogram of dry soil, whereas 16.7 mgm. was present after 20 days. After 98 days 1.3 mgm. of nitrate nitrogen was found in the soils which received sodium nitrate, but none was present in

the bottles which received ammonium sulfate. The presence of small amounts of nitrate is probably due to the neutralization of a part of the soil acidity by the sodium, causing a reaction just within the limit where nitrification occurred.

It may be of interest to describe an experiment to determine the degree in which molds could participate in cellulose fermentation. Five grams of cellulose were placed in each of two bottles. To one bottle was added 10 cc. of the sodium nitrate solution—containing 39 mgm. of nitrate nitrogen—used in the preceding experiment, and to the other was added 10 cc. of the ammonium sulfate solution containing the same amount of nitrogen. Both bottles were inoculated with 0.5 gm. of soil and incubated at 40°C. Within 3 days the bottle to which ammonium sulfate had been added showed a very heavy mold growth, and within 50 days all of the cellulose in this bottle had been completely fermented. Microscopic preparations failed to indicate the presence of bacteria. No visible fermentation of cellulose occurred in the bottle to which the nitrate had been added. It is very likely that at the temperatures under which the experiments were conducted the fermentation due to molds is much greater than occurs under natural soil conditions.

The practical applications of these experiments are numerous, interesting illustrations of the deleterious influence of cellulose in newly cleared land having been cited in the work of Fred and Viljoen (8), of Söderbaum and Barthel (13), and of Gibbs and Werkman (9). Another particularly interesting example is given by Arrhenius (1) in the case of a market gardener who in preparing his forcing beds used heavy applications of shavings which had been used for stable bedding. The cellulose in this bedding brought about a lack of nitrogen in the soil as it underwent fermentation and the young plants were rapidly dying of nitrogen starvation when the attention of the botany department of the experiment station was called to the situation. The crop was saved by the application of sodium nitrate to the soil.

Summary

Cellulose is decomposed in the soil at a rate which increases with the increase in available nitrogen until the latter is present in amounts necessary for the maximum growth of microörganisms. For the conditions of the experiments described in this paper, this point was reached when the ratio of nitrogen to cellulose was about 1:35. When the nitrogen is present in amounts in excess of this ratio it seems to have little influence on the course of the fermentation.

The amounts of cellulose fermented per milligram of nitrogen utilized are not constant but decrease rapidly as the nitrogen increases; in other words, the bacteria are most efficient when their nitrogen supply is limited.

Nitrification can proceed in the presence of cellulose, but unless nitrogen is present in quantities above that required by the bacteria the nitrates are utilized as rapidly as they are formed.

Ammonia can serve as a source of nitrogen for cellulose-fermenting organisms without first being converted to nitrates. Since ammonia was present in cel-

lulose-containing soils when all of the nitrates had been utilized, it appears that the ammonification process continues in the presence of cellulose.

It thus appears that none of the soil processes are inhibited by the addition of carbohydrates to the soil; this is to be expected, for the carbohydrates are not toxic to these organisms. What occurs in the presence of the cellulose is that conditions in the soil are improved for the development of microorganisms and these in turn utilize the available nitrogen for their growth, the nitrogen usually becoming a limiting factor. The growing plant appears to be quite unable to compete with the microörganisms, hence the crop failures on soils containing cellulose.

PART II

It is thought fitting to record here an experiment conducted for the purpose of obtaining some information concerning the availability, for the cellulose fermentation, of organic nitrogen such as would be present in the protein residues returned to the soil under natural conditions or obtained as cleavage products from such residues.

As this experiment was commenced before those described in part I, no information was to be had concerning the influence of the more firmly bound nitrogen on this fermentation. It was thought that protein nitrogen was rendered available more slowly than seems to be the case. For this reason also it was difficult to determine when the analyses should be made, and consequently the 91-day period of incubation was much longer than necessary. Whether a shorter period would have brought out greater differences in the degrees of fermentation in the various bottles is not certain.

The experiment was conducted in exactly the same manner as those described in part I. The substances chosen for study were: ammonium sulfate, urea, aspartic acid, asparagine, alanine, tyrosine, peptone, casein, and stable manure. These substances were added to the soil in amounts such that their available nitrogen, in the case of casein total nitrogen, was equal to the ammonia added in a 2 per cent application of stable manure. For the ammonium sulfate, peptone, casein, and manure, the nitrogen values given in table 5 were obtained by analysis; for the other compounds, these values were calculated according to formula, only the purest compounds obtainable being used. One per cent of cellulose and the amounts of nitrogenous material equivalent to the values given in the table were added to the soil, which was then brought to its optimum water content of 18 per cent. Soluble compounds were added as solutions. After 91-days incubation at 18°C. the soils were analyzed for cellulose with the results indicated in table 5. All figures are the average of two closely agreeing analyses from two soils receiving similar treatment, with the exception of the soils to which aspartic acid had been added. One of the latter had an exceedingly great mold growth and contained only 7.6 per cent of cellulose at the time of analysis.

The conclusions drawn from this experiment are: that the nitrogen present in the natural residues and returned to the soils either in the form of dead vegetation or manure is more available for the cellulose fermentation than was previously supposed, and that the accelerating influence of such compounds on this process is directly proportional to their rate of ammonification. Once the protein is hydrolyzed to the amino acid stage its nitrogen seems to be practically as available as ammonia. The rate of cellulose decomposition is dependent then, not only on the ammonia and nitrate nitrogen in the soil, but also on the rate of decomposition of the more complex nitrogen-containing compounds, as illustrated by the soils containing peptone, casein, and manure.

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THE EFFECTS OF VARIOUS METHODS OF APPLYING FERTILIZERS ON CROP YIELDS[1]

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The effects of various methods of applying fertilizers on plant growth and on certain soil conditions have been considered in another publication (1). In this paper the results of field tests will be given, showing the influence of various fertilizers, applied in different ways, on some important farm crops.

The fertilizers used included acid phosphate (16 per cent), commercial brands secured from different sources, and home mixtures prepared from nitrate of soda, acid phosphate and muriate of potash. Unless otherwise stated, the 0-12-2 and 0-12-0 used were the home mixtures, whereas the 2-12-2 was Armour's Big Crop brand.

EXPERIMENTAL

Oats and clover on Carrington loam

This experiment was carried out on the Agronomy Farm to study the two methods of applying fertilizers, drilled in the rows, *direct contact with the seed* and drilled as a separate operation to the seeding or *broadcast*. A Peoria-Union fertilizer grain drill was used. Iogren oats and Shield Brand medium red clover were seeded. The fertilizer treatments varied as shown in table 1, 200 pounds per acre of 16 per cent acid phosphate being taken as the normal application and the other fertilizers being applied to carry equivalent P_2O_5.

On all the fertilized plots the oats matured earlier than on the checks. The 2-12-2 and 0-12-2 ripened from 4 to 7 days before the 0-16-0 and from 7 to 10 days earlier than the checks. Further, all of the *drilled in row* fertilizer treatments matured 3 to 6 days earlier than the *broadcast* treatments.

From the oats yields in the table it seems evident that drilling the fertilizer *direct contact in the seed rows* was better than *broadcasting* it. Such results do not mean, however, that true broadcasting (using a limesower and discing in the fertilizer, for instance) may not prove equal or even superior to the *drilled in row* method under other conditions.

The fertilizer applications to the clover gave a good stand and crop, whereas the stand and yields on the check plots were very poor. Increased rates of

[1] Part II of a thesis presented to the faculty of the Iowa State College in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

fertilizer application apparently produced larger weights of hay, also, in most instances. No one of the fertilizer brands used consistently out-yielded the others, but the acid phosphate seemed to give the most economical returns.

The data from this study do not warrant a conclusion concerning the better method of applying the fertilizer to clover. The *separate operation* or *broadcast* method gave as good fertilizing benefits as the *direct contact in the seed row* method.

TABLE 1

Oats and clover fertilizer study on Carrington loam

PLOT NUMBER	FERTILIZER TREATMENTS		ACRE YIELDS OF OATS GRAIN (32 POUNDS)	INCREASES BY INTERPOLATION METHOD	ACRE YIELDS OF CLOVER	INCREASES BY INTERPOLATION METHOD
	Analysis	Application	*bushels*	*bushels*	*pounds*	*pounds*
1	None	Check	29.4		794	
2	2-12-2	Drilled in row 0.5 *N**	48.8	18.1	1,802	900
3	0-12-2	Drilled in row 0.5 *N*	52.1	20.1	2,018	1,009
4	0-16-0	Drilled in row 0.5 *N*	55.8	22.5	2,234	1,117
5	None	Check	34.7		1,225	
6	2-12-2	Drilled in row *N*	52.0	14.3	2,380	1,244
7	0-12-2	Drilled in row *N*	63.3	22.6	1,875	829
8	0-16-0	Drilled in row *N*	52.7	9.0	1,802	846
9	None	Check	46.7		866	
10	2-12-2	Broadcast 0.5 *N*	50.4	7.0	1,370	613
11	0-12-2	Broadcast 0.5 *N*	53.2	13.1	1,945	1,296
12	0-16-0	Broadcast 0.5 *N*	41.2	4.3	1,514	974
13	None	Check	33.6		432	
14†	2-12-2	Broadcast *N*	58.6	25.0	1,920	1,542
15†	0-12-2	Broadcast *N*	44.3	10.7	1,685	1,361
16	0-16-0	Broadcast *N*	41.4	7.8	1,945	1,675
17	None	Check	33.6		216	
18	0-16-0	Drilled in row 0.25 *N*	45.4	11.8	1,370	1,046
19	0-16-0	Drilled in row 2 *N*	58.1	24.5	3,320	2,888
20	2-12-2	Drilled in row 2 *N*	64.8	31.2	3,675	3,135
21	None	Check			649	

* *N* = Normal application of 200 pounds of 16 per cent acid phosphate per acre.

† Shorter plots, due to accidental double-seeding in two spots which were discarded.

Oats on O'Neill loam

Table 2 gives the outline of and crop yields in this experiment, which was conducted on a farm near Ames. Iogren oats were drilled with a Van Brunt fertilizer grain drill, and medium red clover seed was sown at the same time. The broadcast applications of the fertilizers were made with a Superior limesower and then worked into the soil by the grain drill. The acid phosphate treatments were reduced from 0-16-0 to 0-12-0 in all cases, so that the same drill or limesower set could be used as was employed in the 0-12-2 and 2-12-2 brands. For the *above* fertilizer treatments, the delivery pipes of another

drill were attached to the Van Brunt drill so that the fertilizer fell partly into the row in *direct contact with the seed* but chiefly *above the seed with soil interposed.*

Although this test failed to show very pronounced fertilizer responses, some interesting facts are indicated. Drilling the fertilizer *direct contact in the seed*

TABLE 2

Oats fertilizer study on O'Neill loam

PLOT NUMBER	FERTILIZER APPLICATION			ACRE YIELDS OF GRAIN (32 POUNDS)	ACRE INCREASES BY INTERPOLATION METHOD
	Analysis	Rate per acre	Method		
		pounds		*bushels*	*bushels*
1	Check	None		34.1	
2	2-12-2	100	Drilled in seed rows	40.9	6.6
3	2-12-2	100	Broadcast with limesower	34.1	−0.4
4	0-12-0	100	Broadcast with limesower	32.9	−1.9
5	0-12-0	100	Drilled in seed rows	38.6	3.6
6	Check	None		35.2	
7	0-12-0	400	Broadcast with limesower	37.4	1.8
8	0-12-0	200	Drilled in seed rows	44.3	8.2
9	0-12-2	200	Drilled in seed rows	43.1	6.6
10	0-12-2	400	Broadcast with limesower	40.9	3.9
11	Check	None		37.4	
12	0-12-2	100	Drilled in seed rows	43.1	5.2
13	0-12-2	100	Broadcast with limesower	37.4	−0.9
14	0-12-2	100	Drilled—separate operation— 2 inches deep)	39.7	0.9
15	0-12-2	100	Drilled in seed rows (2 inches deep)	46.5	7.3
16	Check	None		39.7	
17	0-12-2	200	Drilled *above* seed through second set delivery pipes	38.6	−1.6
18	0-12-2	200	Drilled—separate operation—(½ inch deep)	42.0	1.4
19	0-12-2	200	Drilled—separate operation—(2 inches deep)	45.4	4.3
20	0-12-2	200	Drilled—separate operation—(4 inches deep)	47.7	6.2
21	Check	None		42.0	
22	0-12-0	200	Drilled—separate operation—(4 inches deep)	52.2	9.4
23	0-12-0	200	Drilled *above* seed through second set delivery pipes	44.3	0.6
24	0-12-0	200	Drilled in seed rows (2 inches deep)	54.5	10.0
25	Check	None		45.4	
26	2-12-2	200	Drilled in seed rows (2 inches deep)	55.6	10.2
27	2-12-2	200	Drilled *above* seed through second set delivery pipes	51.1	5.7
28	2-12-2	200	Drilled—separate operation—(4 inches deep)	54.5	9.1
29	Check	None		45.4	
30	2-12-2	400	Drilled in seed rows	60.2	15.5
31	2-12-2	100	Drilled in seed rows	46.5	2.6
32	Check	None		43.1	

row with the grain drill was better than *broadcasting* with a limesower. *Broadcast* applications of 100 pounds per acre failed to give increased yields over the checks, and 400 pounds *broadcast* did not yield as much as 200 pounds drilled *direct contact.* Drilling the fertilizer as a *separate operation to the seeding* was

slightly better than *broadcasting* it with a limesower. Where the *separate operation* method was used, the depth of fertilizer application relative to the seed appeared important. Drilling the fertilizer *above* the seed through a second set of delivery pipes gave very small benefits.

Winter wheat on Carrington loam

In this experiment on the Agronomy Farm, a special 2-12-2 mixture deriving its ammonia one-half from calcium cyanamid and one-half from dried blood, was prepared for comparison with Armour's 2-12-2 Big Crop brand.

Iobred wheat was used at the rate of 1½ bushels per acre. Each plot was 1 drill strip wide and 163.5 feet long, or $\frac{1}{88}$ acre in size. The fertilizer applications were made with a Peoria-Union drill for the row methods and with a Peoria limesower for the broadcast.

From the results given in table 3, some significant facts may be noted. Four hundred pounds per acre of Cyanamid 2-12-2 fertilizer applied *direct contact in the seed row* gave an increase over the adjacent check but the increase was smaller than that given by the fertilizer applied in safer ways. Four hundred pounds per acre of the commercial 2-12-2 drilled *direct contact* also depressed the yield when compared to the same treatment applied *broadcast*. The injury was not so pronounced, however, as in the case of the fertilizer containing Cyanamid.

Two hundred pounds per acre of 0-12-2 drilled *direct contact* gave the best yields. The same amount of 0-12-0 similarly applied was almost as effective. Four hundred pounds *broadcast* was not so beneficial as 200 pounds *direct contact*. Drilling the fertilizer as a *separate operation to the seeding* gave benefits equal to those of the limesower *broadcast* method. The separate drilling failed to equal the *direct contact in the seed rows* method for moderate amounts of the non-caustic fertilizers.

Fall applications of fertilizers were more beneficial than spring applications. Splitting the fertilizer between fall and spring applications did not appear to be economical.

Applying the fertilizer 10 days in advance of seeding gave good results for the Cyanamid mixture, but was of no value for the other fertilizers studied. The depth study showed that locating fertilizers (particularly acid phosphate) shallower than the seed at planting time was not so beneficial as locating them at the same depth or slightly deeper than the seed.

Fertilizer depth study with winter wheat on Carrington loam

In this experiment on a farm near Ames, the depth factor of fertilizer location relative to the seed was studied. The fertilizer was applied with the Peoria-Union grain drill on the day of seeding, but as a *separate operation to sowing the Iobred wheat*. The plots were 530 feet long and 1 drill strip wide, or approximately $\frac{1}{12}$ acre.

TABLE 3

Winter wheat fertilizer study on Carrington loam

PLOT NUMBER	FERTILIZER TREATMENTS			ACRE YIELD OF GRAIN (60 POUNDS)	ACRE INCREASES BY INTERPOLATION METHOD
	Analysis	Application			
		Rate per acre	Method		
		pounds		*bushels*	*bushels*
1	Check	None		31.6	
2	2–12–2 (Cyanamid)	400	Broadcast wth limesower	38.0	6.3
3*	2–12–2 (Cyan.)	400	Broadcast with limesower	39.2	7.4
4*	2–12–2 (Cyan.)	400	Drilled	38.0	6.0
5	2–12–2 (Cyan.)	400	Drilled—separate operation	38.0	5.9
6	2–12–2 (Cyan.)	400	Drilled in seed rows	34.8	2.6
7	Check	None		32.3	
8*	0–12–2	400	Broadcast with limesower	37.7	5.1
9	0–12–2	400	Broadcast with limesower	39.9	7.1
10	0–12–2	200	Drilled in seed rows	44.6	11.5
11	0–12–0	200	Drilled in seed rows	43.0	9.6
12	0–12–0	400	Broadcast with limesower	39.6	5.9
13*	0–12–0	400	Broadcast with limesower	39.2	5.3
14	Check	None		34.2	
15†	2–12–2 (Commercial)	400	Broadcast with limesower	36.1	1.7
16	2–12–2 (Com.)	400	Broadcast with limesower	44.3	9.7
17	2–12–2 (Com.)	400	Drilled in seed rows	42.1	7.2
18*	2–12–2 (Com.)	400	Drilled	42.4	7.3
19	2–12–2 (Com.)	400	Drilled—separate operation	43.0	7.6
20†	2–12–2 (Com.)	400	Drilled	38.0	2.4
21	Check	None		35.8	
22†	0–12–2	400	Drilled	36.4	0.8
23	0–12–2	400	Drilled—separate operation	37.3	2.0
24	0–12–2	400	Drilled in seed rows	40 2	5.2
25	0–12–0	400	Drilled in seed rows	38.6	3.9
26†	0–12–0	400	Drilled	36.1	1.7
27	Check	None		34.2	
28	2–12–2 (Commercial)	400	Half drilled in seed rows in fall Half drilled in spring	36.7	2.5
29	2–12–2 (Com.	200	Drilled in seed rows	38.0	3.8
30	2–12–2 (Com. †0–12–2	200 200	Drilled in seed rows Drilled	37.3	3.0
31	2–12–2 (Commercial)	400	Drilled in seed rows (2 inches deep)	40.5	6.2
32	2–12–2 (Com.)	400	Drilled—separate operation (½ inch deep)	37.3	2.9
33	2–12–2 (Com.)	400	Drilled—separate operation (4 inches deep)	38.3	3.9
34	Check	None		34.5	

* Fertilizer applied 10 days before seeding.

† Fertilizer applied in the spring.

The data in table 4 show that drilling the fertilizer *direct contact in the seed rows* was superior to drilling the same fertilizer as a *separate operation to the seeding,* no matter what depth was used in the drilling. Even 100 pounds per

TABLE 4

Fertilizer depth study with winter wheat on Carrington loam

PLOT NUMBER	FERTILIZER TREATMENTS				ACRE YIELDS OF GRAIN (60 POUNDS)	ACRE INCREASES BY INTERPOLATION METHOD
	Analysis	Application				
		Rate per acre	Depth	Method		
		pounds	*inches*		*bushels*	*bushels*
1	Check	None			29.4	
2	2-12-2 (Cyanamid)	400	½	Drilled—separate operation after seeding	36.8	6.3
3	2-12-2 (Cyan.)	400	2	Drilled—separate operation	39.8	8.2
4	2-12-2 (Cyan.)	400	4	Drilled—separate operation before seeding	41.1	8.3
5	2-12-2 (Cyan.)	400	2	Drilled in seed rows	43.9	9.9
6	2-12-2 (Cyan.)	100	2	Drilled in seed rows	41.7	6.5
7	Check	None			36.4	
8	2-12-2 (Commercial)	400	½	Drilled—separate operation after seeding	37.6	2.8
9	2-12-2 (Com.)	400	2	Drilled—separate operation	38.8	5.6
10	2-12-2 (Com.)	400	2	Drilled in seed rows	41.5	9.9
11	2-12-2 (Com.)	400	4	Drilled—separate operation before seeding	37.8	7.8
12	2-12-2 (Com.)	100	2	Drilled in seed rows	37.2	8.8
13	Check	None			26.8	
14	0-12-0	400	½	Drilled—separate operation after seeding	29.4	1.2
15	0-12-0	400	2	Drilled in seed rows	37.8	8.2
16	0-12-0	400	2	Drilled—separate operation	37.0	6.0
17	0-12-0	400	4	Drilled—separate operation before seeding	35.5	3.0
18	Check	None			33.9	
19	0-12-0	100	2	Drilled in seed rows	38.8	5.5
20	0-12-2	100	2	Drilled in seed rows	40.0	7.2
21	0-12-2	400	½	Drilled—separate operation after seeding	35.6	3.4
22	0-12-2	400	2	Drilled—separate operation	36.0	4.3
23	0-12-2	400	4	Drilled—separate operation before seeding	37.2	6.1
24	0-12-2	400	2	Drilled in seed rows	38.0	7.5
25	Check	None			30.0	

acre of the fertilizers drilled *direct contact* always proved equal to or slightly better than 400 pounds of the same fertilizer applied as a *separate operation.* Little increase in yield over the 100-pound applications was found for the 400-pound treatments *direct contact.*

The conclusion appears warranted that applications of fertilizers shallower than the seed were not equal in benefits to applications on the same plane with the seed or slightly deeper.

Winter wheat on Tama silt loam

This experiment was carried out on Tama silt loam in Adair County. Table 5 gives the outline of the test and the yields obtained. Turkey Red wheat was

TABLE 5

Winter wheat fertilizer study on Tama silt loam

PLOT NUMBER	FERTILIZER TREATMENTS			ACRE YIELDS OF GRAIN (60 POUNDS)	ACRE INCREASES OF GRAIN OVER AVERAGE OF CHECKS
	Analysis	Application			
		Rate per acre	Method		
		pounds		*bushels*	*bushels*
			Large acreage test		
1	Check	None		11.5	
2	2-12-2	200	Drilled—separate operation	15.7	3.9
3	2-12-2	200	Drilled in seed rows	21.2	9.4
4	2-12-2	200	Drilled in spring	15.1	3.3
5	Check	None		12.1	
			Small plot test		
1	Check	None		12.1	
2	2-12-2	300	Drilled in seed rows	15.7	4.5
3	2-12-2	100	Drilled in seed rows	14.5	3.3
4	2-12-2	200	Drilled in seed rows	20.6	9.4
5	2-12-2	200	Drilled half in fall, half in spring	16.3	5.1
6	2-12-2	300	Drilled, 200 pounds in fall, 100 pounds in spring	16.9	5.7
7	2-12-2 0-12-0	200 100	Drilled in seed rows in fall Drilled in spring	18.8	7.6
8	0-12-0	300	Drilled, 200 pounds in fall, 100 pounds in spring	17.6	6.4
9	0-12-0	200	Drilled, half in fall, half in spring	15.7	4.5
10	0-12-0	200	Drilled in seed rows	20.0	8.8
11	0-12-0	100	Drilled in seed rows	15.7	4.5
12	0-12-0	300	Drilled in seed rows	17.6	6.4
13	Check	None		10.3	

seeded at the rate of 1½ bushels per acre with a Moline fertilizer grain drill. The large acreage portion of the experiment consisted of 5 plots, each 98 feet wide and 660 feet long, or approximately 1½ acre in size. In the small plot test each plot was 1 drill width across the field. The complete commercial fertilizer, 2-12-2, was furnished by the American Agricultural Chemical Company.

In the large acreage test, it is evident that drilling the fertilizer *direct contact in the seed rows* was preferable to either fall or spring *separate operation* drilling. On the small plots, the 200-pound applications drilled in *direct contact* again gave the best yields. The 300-pound treatments showed depressions in yields, being scarcely better than the 100-pound applications. The combinations of fall plus spring applications failed to equal the yields with fall applications alone, even where 300 pounds applied in this way was compared to 200 pounds applied in the fall. It will be noted in both parts of this study that the best application of the fertilizer practically doubled the yields over that on the check plots.

TABLE 6

Winter wheat fertilizer study on Tama silt loam II

PLOT NUMBER	FERTILIZER TREATMENTS			ACRE YIELDS OF GRAIN (60 POUNDS)	ACRE INCREASES BY INTERPOLATION METHOD
	Analysis	Application			
		Rate per acre	Method		
		pounds		*bushels*	*bushels*
1	Check	None		10.3	
2*	2-12-2	300	Drilled	12.1	1.9
3	2-12-2	300	Drilled—separate operation (2 inches deep)	16.9	6.9
4	2-12-2	300	Drilled in seed rows (2 inches deep)	22.4	12.6
5	Check	None		9.7	
6	2-12-2	100	Drilled in seed rows (2 inches deep)	16.9	6.6
7	2-12-2	300	Drilled—separate operation (½ inch deep)	16.3	5.4
8	2-12-2	300	Drilled—separate operation (2 inches deep)	17.6	6.1
9	2-12-2	300	Drilled—separate operation (4 inches deep)	17.6	5.5
10	Check	None		12.7	
11	0-12-0	300	Drilled—separate operation (½ inch deep)	18.2	6.4
12	0-12-0	300	Drilled—separate operation (2 inches deep)	16.9	6.0
13	0-12-0	100	Drilled in seed rows (2 inches deep)	18.8	8.9
14	0-12-0	300	Drilled—separate operation (4 inches deep)	18.2	9.3
15	Check	None		7.9	
16	0-12-0	300	Drilled in seed rows (2 inches deep)	19.3	10.8
17	0-12-2	300	Drilled in seed rows (2 inches deep)	18.2	9.1
18	0-12-2	100	Drilled in seed rows (2 inches deep)	14.5	4.8
19	0-12-2	300	Drilled—separate operation (2 inches deep)	15.7	5.4
20*	0-12-2	300	Drilled	12.7	1.8
21	Check	None		11.5	

* Fertilizer applied in the spring.

Winter wheat on Tama silt loam II

This test was conducted on another farm in Adair County. Kanred wheat was seeded at the rate of 1½ bushels to the acre and drilled in with the Moline fertilizer grain drill, on plots of 1 drill width each. The 2-12-2 fertilizer was Armour's Big Crop brand.

The results given in table 6 show that drilling the fertilizer *direct contact*

in the seed rows was better than drilling it as a *separate operation* either in the fall or in the spring. Indeed, the *direct contact* plots averaged 20 bushels per acre, whereas the unfertilized checks averaged only 10.4 bushels and the spring applications averaged 12.4 bushels. The most economical treatment was the 100 pounds per acre of 0-12-0.

The depth study indicated that shallow fertilizer applications were not equal to similar ones located on the same plane with the seed or even slightly deeper.

Winter wheat on Grundy silt loam

This experiment was located in Wapello County. Since no fertilizer grain drill was available, the applications were made with a Holden, rear end-gate broadcast fertilizer and limestone distributor. It was planned to compare the two common methods of working the fertilizer into the soil after it

TABLE 7
Winter wheat fertilizer study on Grundy silt loam

PLOT NUMBER	FERTILIZER APPLICATION			ACRE YIELDS OF GRAIN (60 POUNDS)	ACRE INCREASES BY INTERPOLATION METHOD
	Analysis	Rate per acre	Method		
		pounds		*bushels*	*bushels*
1	Check	None		36.3	
2	2–12–2	400	Broadcast and disced in	46.0	10.3
3	0–12–0	400	Broadcast and disced in	38.7	3.6
4	0–12–2	400	Broadcast and disced in	43.0	8.5
5	Check	None		33.9	
6	2–12–2	400	Broadcast and harrowed in	40.6	7.2
7	0–12–0	400	Broadcast and harrowed in	35.7	2.7
8	0–12–2	400	Broadcast and harrowed in	40.0	7.5
9	Check	None		32.1	

had been applied broadcast, *discing in* versus *harrowing in*. The results of the experiment are given in table 7.

The harvest yields showed that the *discing* method gave larger yields than the *harrowing* method for all of the fertilizers tested. For light sandy soils in a rainy season, the results might be reversed, but for the average soil of the cornbelt the thorough discing in of the fertilizer appears desirable.

Corn on Carrington loam I

This experiment was carried out on the Agronomy Farm. Table 8 gives the outline with the harvest data. The *hill* fertilization was attained with the standard attachment on a John Deere No. 999 corn planter, which instead of depositing the fertilizer *in the hill*, spread the fertilizer as a strip approximately 1 to 1½ inches wide and 3 to 6 inches long at a distance of 3 inches *to the rear* of the hills.

The plots were 4 rows wide or 2 drill widths of 7 feet each. Reid's Yellow Dent was used and the seed was planted about 2½ inches deep. The broadcast fertilizer was drilled only to moisture.

In considering the harvest results, emphasis should be placed on the fact that the *rear of hill* location for the fertilizer gave 3 to 7 days earlier maturity than the *broadcast* treatments. For maximum yields and superior quality of corn, however, the *broadcast* treatments appeared the better.

TABLE 8

Corn fertilizer study on Carrington loam I

PLOT NUMBER	FERTILIZER TREATMENTS		ACRE YIELDS OF CORN (70 POUNDS)	ACRE INCREASES BY INTERPOLATION METHOD
	Analysis	Application		
			bushels	*bushels*
1	None	Check	77.1	
2	2-12-2	Broadcast 0.5 *N**	83.3	6.1
3	0-12-2	Broadcast 0.5 *N*	79.0	1.6
4	0-16-0	Broadcast 0.5 *N*	77.9	0.3
5	None	Check	77.7	
6	2-12-2	Broadcast *N*	83.3	7.9
7	0-12-2	Broadcast *N*	83.9	10.8
8	0-16-0	Broadcast *N*	72.9	2.1
9	None	Check	68.5	
10	2-12-2	Hill 0.5 *N*	78.0	8.9
11	0-12-2	Hill 0.5 *N*	79.9	10.2
12	0-16-0	Hill 0.5 *N*	73.0	2.7
13	None	Check	70.9	
14	2-12-2	Hill *N*	72.3	1.7
15	0-12-2	Hill *N*	69.9	−0.5
16	0-16-0	Hill *N*	67.6	−2.5
17	None	Check	69.8	

* *N* = normal application of 200 pounds of 16 per cent acid phosphate per acre, taken as basis for applications.

Corn on Carrington loam II

This experiment was carried out the following year on the same land used in the preceding test. A slight change in the order of arranging the fertilizer treatments was made, the 0-12-0 mixture being placed between the 2-12-2 and the 0-12-2, to determine whether potash had any influence upon the corn yields. The acid phosphate, or 0-16-0, used in the first year was diluted to an 0-12-0 mixture. The number of plots was increased for a more complete test.

Table 9 gives the outline of the experiment with the harvest yields. The corn was planted with a John Deere No. 999 fertilizer corn planter. The plots were 4 corn rows wide, or 14 feet, and about 100 hills long, so that $\frac{1}{10}$-acre plots might be harvested. The *broadcast* fertilizer treatments were made with the Peoria-Union fertilizer grain drill after the corn had been planted. The *hill* applications were made with a new attachment designed by the writer and

connected to the seed shanks. It consisted of two regular attachments joined by iron braces and operated by the checkwire simultaneously with the seed valves. It applied the fertilizer partly in *direct contact* and partly along *both sides* of the hills as desired, and although it was not perfect because the poor furrow openers used increased the draft considerably, it served to give some interesting comparisons.

From the harvest data it appears that the potash applications with acid phosphate gave benefits in all cases. The 2-12-2 fertilizer showed up better

TABLE 9

Corn fertilizer study on Carrington loam II

PLOT NUMBER	FERTILIZER APPLICATIONS			ACRE YIELDS OF CORN (70 POUNDS)	ACRE INCREASES BY INTER-POLATION METHOD
	Analysis	Rate per acre	Method		
		pounds		*bushels*	*bushels*
1	Check	None		67.6	
2	2-12-2	134	Broadcast—grain drill	79.6	9.3
3	0-12-0	134	Broadcast—grain drill	80.0	7.0
4	0-12-2	134	Broadcast—grain drill	86.4	10.7
5	Check	None		78.3	
6	2-12-2	267	Broadcast—grain drill	82.4	3.1
7	0-12-0	267	Broadcast—grain drill	86.9	6.6
8	0-12-2	267	Broadcast—grain drill	88.6	7.3
9	Check	None		82.3	
10	2-12-2	134	Both sides of hill	83.3	4.6
11	0-12-0	134	Both sides of hill	75.4	0.4
12	0-12-2	134	Both sides of hill	83.4	12.1
13	Check	None		67.6	
14	2-12-2	267	Both sides of hill	74.0	7.2
15	0-12-0	267	Both sides of hill	62.7	−3.2
16	0-12-2	267	Both sides of hill	71.9	6.9
17	0-12-2	267	Broadcast—grain drill	69.2	5.1
18	Check	None		63.2	
19	0-12-2	134	Both sides of hill	74.8	13.2
20	0-12-2	134	Broadcast—grain drill	67.0	6.9
21	0-12-2	134	Rear of hill	68.8	10.3
22	Check	None		57.0	

in the *hill* plots than in the *broadcast* plots when compared to the adjacent 0-12-0 plots, but failed to equal the results secured with the 0-12-2 treatments in most cases. With the latter mixture the *hill* method out-yielded the *broadcast* method. Hill fertilization upon *both sides* by the new attachment was better than *to the rear* with the standard attachment. The economy of smaller applications located at the hill is shown also in this test. For early maturity the hill method of corn fertilization again proved itself superior to broadcasting.

Corn on Carrington loam III

The outline of this test is presented in table 10, with the harvest data. It was carried out on a farm near Ames. Kelly's Improved seed corn was used.

TABLE 10

Corn fertilizer study on Carrington loam III

PLOT NUMBER	FERTILIZER APPLICATIONS			ACRE YIELDS OF CORN (70 POUNDS)	ACRE INCREASES BY INTERPOLATION METHOD
	Analysis	Rate per acre	Method		
		pounds		*bushels*	*bushels*
1	Check	None		48.9	
2	2–12–2	100	Both sides of hill	50.3	1.7
3	2–12–2	100	One side of hill	47.4	−1.0
4	2–12–2	100	Continuous in row, falling upon "deflectors" at bottom of delivery pipes	48.6	0.5
5	2–12–2	100	Continuous in row, direct contact	45.7	−2.2
6	Check	None		47.6	
7	2–12–2	200	200 pounds 0–12–2 broadcast (limesower) 21.3 pounds $NaNO_3$ both sides of hill	12.4a 35.7b 48.1	0.6
8	2–12–2	200	150 pounds broadcast (lime sower) and 50 pounds both sides of hill	51.9	4.5
9	2–12–2	200	Both sides of hill	52.1	4.8
10	2–12–2	200	Broadcast (limesower)	50.1	3.0
11	Check	None		47.0	
12	2–12–2	150	150 pounds 0–12–2 broadcast (grain drill) 16 pounds $NaNO_3$ both of sides hill	17.1a 25.6b 42.7	−4.3
13	2–12–2	150	Broadcast (grain drill)	45.7	−1.3
14	2–12–2	150	100 pounds broadcast (grain drill) and 50 pounds both sides of hill	46.6	−0.3
15	2–12–2	300	200 pounds broadcast (grain drill) and 100 pounds both sides of hill	44.0	−2.9
16	Check	None		46.9	
17	2–12–2	300	Broadcast (grain drill)	49.9	3.1
18	2–12–2	100	Both sides of hill	51.3	4.6
19	2–12–2	100	Rear of hill	47.6	1.0
20	2–12–2	300	Broadcast (limesower)	47.7	1.2
21	Check	None		46.4	
22	2–12–2	100	Broadcast (limesower)	49.1	2.8
23	2–12–2	100	One side of hill	51.6	5.4
24	2–12–2	100	Rear of hill	48.4	2.3
25	2–12–2	100	Broadcast (grain drill)	48.4	2.4
26	Check	None		45.9	

a = 2 inside rows.
b = 2 outside rows.

The plots were $\frac{1}{16}$ acre in size, 4 rows wide and 89 hills long. Plot 23 was intended to be a *both sides of the hill* treatment but as one of the rods operating the fertilizer dump valves on the right seed shank broke, the treatment was

TABLE 11

Potato fertilizer study on Carrington fine sandy loam

PLOT NUMBER	METHODS OF FERTILIZER APPLICATION (1600 POUNDS PER ACRE OF 3-12-4)	ACRE YIELDS	ACRE INCREASES BY INTERPOLATION METHOD
		bushels	*bushels*
1	Check—unfertilized	155.0	
2	*Sides lower plane*—narrow spread	217.0	61.7
3	¼ fertilizer *below* seed and ¾ at *sides same plane*—narrow spread	201.0	45.4
4	¾ fertilizer in *made-up ridge* ahead of planting and ¼ at *sides same plane*—narrow spread	187.5	31.6
5	½ fertilizer in *made-up ridge* ahead of planting and ½ at *sides same plane*—narrow spread	199 5	43.3
6	Check—unfertilized	156.5	
7	*Made-up ridge* ahead of planting	194.5	39.7
8	*Sides same plane*—wide spread	192.5	39.4
9	*Sides same plane*—narrow spread	205 0	53.6
10	*Made-up ridge* ahead of planting	172 0	22.3
11	Check—unfertilized	148.0	
12	*Sides same plane*—wide spread	189.0	40.1
13	*Sides lower plane*—narrow spread	215.0	65.2
14	*Sides same plane*—narrow spread	199.5	48.9
15	Check—unfertilized	151.5	
16	¼ fertilizer *below* seed and ¾ at *sides same plane*—narrow spread	198 0	47.8
17	*Above* seed with soil interposed, wide spread	165 0	16.2
18	*Above* seed with soil interposed, narrow spread	161.5	14.1
19	Check—unfertilized	146 0	
20	¼ fertilizer *above* seed and ¾ at *sides same plane*—narrow spread	182.5	38.9
21	*Direct contact* in row (1600 pounds per acre)	117.0	−24.2
22	*Mixed with soil in row* (1600 pounds per acre)	131.0	−7.8
23	*Direct contact in row* (400 pounds per acre)	149.5	13.1
24	Check—unfertilized	134.0	
	(0–16–0 applied in this part of the study)		
25	*Direct contact* in row (400 pounds per acre)	137.5	1.2
26	*Sides same plane*, narrow spread (400 pounds per acre)	168.5	29.9
27	Check-unfertilized	141.0	
28	*Made-up ridge* ahead of planting (400 pounds per acre)	172 0	31.3
29	*Above* seed with soil interposed, wide spread (400 pounds per acre)	146.0	5.7
30	¼ fertilizer *above* seed and ¾ at *sides same plane*, narrow spread (400 pounds per acre)	170.5	30.6
31	Check—unfertilized	139.5	
32	*Sides same plane*—narrow spread (1200 pounds per acre)	179.0	37.8
33	*Sides same plane*—narrow spread (1600 pounds per acre)	180.5	37.6
34	*Sides same plane*—narrow spread (800 pounds per acre)	179.0	34.4
35	*Sides same plane*—narrow spread (2400 pounds per acre)	191.0	44.7
36	Check—unfertilized	148.0	

one side of hill. The *side-hill* attachment on the right seed shank was set in too closely, so that a part of the fertilizer fell in *direct contact* with the corn kernels in the hill. This location proved quite injurious to the germination where the nitrate of soda was checked at the hills in plots 7 and 12. The outer rows of these plots planted with the left shank were of average stand.

The yields obtained in this experiment are small, but the comparisons are quite definite. The conclusion seems warranted that the *hill* methods of fertilizer application were better than the *broadcast* methods. The *sides of hill* location also seemed superior to the *rear of hill* location. No conclusions can be drawn from the results with the *split* applications

Potatoes on Carrington fine sandy loam

This experiment was carried out on a farm near Clear Lake, Iowa. Two rows of Rural New Yorker seed were planted in each plot with a 3-foot interval between the rows. The rows were each 64 rods long, thus making plots of approximately $\frac{1}{4}$ acre. A new Iron Age Automatic potato planter was used.

Table 11 gives the outline of the test with the harvest results. The fertilizers used were Armour's 3-12-4 Big Crop brand, and 16 per cent acid phosphate. All of the *made-up ridge* fertilizer applications were secured by using the planter to apply the fertilizer as a separate operation with wide set of the delivery pipes, then shutting off the fertilizer attachment and retracing the ridges to plant the seed. The *mixed with the soil in the row* condition was secured with the same adjustment as in the *direct contact* method, except that a log-chain was looped back and forth from the opening discs and allowed to drag in the seed row just ahead of the seed delivery chute.

It appears from the data in the table, that applications of large amounts of high-analysis, readily-soluble fertilizers *direct contact in the row with the seed* reduced the yields. Applied in this manner, 1600 pounds per acre of fertilizer actually decreased the yield by about 30 bushels below the average of all of the checks. Mixing the same amount of fertilizer with the soil in the row tended to minimize the injury but did not eliminate it.

Applications of small amounts of fertilizer *direct contact in the rows with the seed* sometimes gave increased yields, but the results cannot be said to equal those secured with better methods of application.

The best method of fertilizer application seemed to be the *sides lower plane* location. Increases of over 60 bushels per acre were secured by this method.

The *made-up ridge* plots failed to indicate any definite facts, and no conclusions can be drawn regarding the practice of *splitting* the fertilizer applications.

CONCLUSIONS

These experiments must be repeated upon numerous soil types and over a series of years before definite conclusions can be drawn and a satisfactory

fertilizer practice worked out for each of the various crops. The results reported, however, indicate some very worthwhile suggestions.

In fertilizing cereals like oats and wheat, the use of a combination fertilizer-grain drill is recommended. Moderate applications of non-caustic fertilizers gave the most economical returns by this *direct contact in the seed rows* method. As much as 400 pounds per acre of 16 per cent acid phosphate or 300 pounds of commercial 2-12-2 fertilizer were drilled with the seed without appreciable injury to germination and hence resulting decreased yields.

Larger applications than these or the distribution of fertilizers containing caustic ingredients like Cyanamid, should be made separately from the seeding. The best yields with the Cyanamid came from broadcasting it ten days in advance of the seeding. For large applications of non-caustic fertilizers, the best method appeared to be a splitting of the total application between the *drilled direct contact in the seed rows* method and the *broadcast* method.

These tests showed no advantage in spring applications, either for the entire fertilizer application or for a part of it. The drilling of the fertilizer as a *separate operation to the seeding*, no matter what the depth or the time period before the seeding, was not equal to the *direct contact* method, provided of course moderate amounts of the non-caustic fertilizers were used. The use of a second set of delivery pipes for distributing the fertilizer *above* the seed-row was found to safeguard the germination, but failed to give benefits warranting their adoption. Where *broadcast* applications of fertilizers were made with a limesower or by other means upon the seedbed surface, the best results were secured when the fertilizer was worked into the soil by thorough discing.

In the fertilization of corn, the *hill* methods appeared equal to or even superior to the *broadcast* method if the fertilizer was not delivered *direct contact into the hills with* the seed. Earlier maturity was secured with the hill method.

Comparisons of the two hill methods—the *rear of hill* with the *sides of hill*—indicated that the latter was preferable. It cannot give the *direct contact in the hill* location as the *rear of hill* method often does (because of a deranged adjustment of the fertilizer attachment) and hence the *sides* method is recommended over the *rear* method for preventing injury to seed germination.

A satisfactory design of attachment is needed to guarantee the *sides* location of the fertilizer for all machines sowing seeds in wide rows or in hills, such as corn, cotton, beets, and potatoes. In fact, the *sides lower plane* location for the fertilizer gave the best yields of potatoes in these Iowa tests.

REFERENCE

(1) Coe, D. G. 1926. The effects of various methods of applying fertilizers on crops and on certain soil conditions. *In* Soil Sci., v. 21, p. 7-21.

A COMPARATIVE STUDY OF THE BACTERIAL FLORA OF WIND-BLOWN SOIL: I. ARROYO BANK SOIL, TUCSON, ARIZONA

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INTRODUCTION

Although a considerable amount of work has been done upon the bacteria in soil, no one apparently has made a comparative study of the number and types of bacteria in ecologically equivalent types of soil in different regions. It was, therefore, with this aim in view that the series of studies, of which this is the first, was started. The type of soil selected for the study was arid, wind-blown soil, such as is found in the dunes along the coast and around Lake Michigan, and in the dry regions in the interior of the continent.

In order to facilitate the handling of such a comprehensive piece of work, the approach was made through the study of certain types of aerobic bacteria that grow in ordinary culture media. Should the study of these forms prove to be of value, the work probably will be extended to those forms which require special culture conditions.[1]

METHODS AND MATERIALS

Collection of samples

The soil was collected with a trowel at three places 10 to 15 feet apart, from depths of 6, 12, and 24 inches. It was thoroughly mixed in quart jars, which had previously been scrubbed out with the same soil, one jar being used for each depth.

Study of the soil

Water content. At the time of collection the water content of the soil was determined. The soil was not oven-dried, because of lack of temperature control, but was exposed, with repeated stirrings, to the Arizona sunshine until the weight was constant.

Water capacity. The water capacity was tested some time after the soil was collected. As the quantity of soil was limited, 10 cc. of distilled water was allowed

[1] The work included in the present report was carried on at the Desert Laboratory of the Carnegie Institution of Washington. The author wishes, therefore, to express her deep appreciation of the courtesy and assistance extended by Director MacDougal, and the other members of the laboratory. The photographs of Pantana Wash were taken by Mrs. Strickland and Mr. Godfrey Sykes of the Desert Laboratory.

to percolate through a weighed amount of the oven-dried sample, the percolate was collected, and the capacity was calculated. This was checked by weighing.

Size of soil particles. A rough analysis was made by passing the soil through a series of sieves and bolting cloth with apertures having diameters of 2 mm., 1 mm., 0.5 mm., and approximately 0.124 mm. respectively.

Combustible material. Oven-dried soil was weighed on an asbestos plate of known weight. It was then heated and stirred until there was no further evidence of combustion. After this it was heated a few minutes longer and reweighed. The asbestos plate was also reweighed and the loss calculated.

Reaction of the soil. The importance of the soil reaction became evident when, after the soil had stood almost two years, the test was made. As the soil had been kept perfectly dry during this time, no great chemical change seemed possible. The test was made by adding 1 gm. of soil to 5 cc. of distilled water, as advocated by Joseph and Martin (31) and used by Atkins (4) and others. To the mixture of soil and water was added 10 drops of indicator, made according to Gillespie's directions (25). The mixture was shaken repeatedly for about half an hour. As the soil was light and settled rather quickly, it was not decanted nor centrifuged. After the soil had settled the liquid was matched with the indicator chart of Clark (11).

Water-soluble salts. Considering the chemical composition of the soil, the water-soluble salts, particularly the chlorides, carbonates, sulfates and nitrates, are probably the most significant from the standpoint of bacterial flora. An analysis on this basis was made, therefore, according to the method given in Official and Tentative Methods of Analysis (2).[2]

Plating

Due to an unavoidable delay, the soil was plated 36 hours after collection. Dilutions of 1:10,000; 1:100,000; and 1:1,000,000 were made by shaking the required amount of soil in the proper amount of distilled water, for two or three minutes, and allowing the heavy particles to settle. According to Hiltner and Störmer (28) adequate shaking removes the bacteria from soil particles and a transfer of portions of the soil, as advocated by Wyant (59) is unnecessary. Three, or six, plates were poured from each dilution for each sample, in nutrose agar, made according to a modification of the formula suggested by Waksman and Fred (57). Five-tenths per cent nutrose was used, the sugar was omitted and the salts were supplied by tap water.

Counting

The counting was done with the naked eye, supplemented by a lens whenever threre was any doubt regarding the colonies.

[2] The analysis was made by Miss Miriam Dice, under the direction of Dr. Mary A. Griggs, Associate Professor of Chemistry, Wellesley College, to whom the writer presents her sincere thanks.

Isolation of forms

From the original plates 84 colonies were fished and streaked on nutrose agar. From 4 of these 2 were separated, making a total of 88 streaks. Actinomycetes were avoided in this selection whenever their nature was evident. These cultures were placed in cold storage in Tucson for the summer, and shipped to Wellesley in August.[3] Here those that were still alive were transferred to nutrient agar (made from 1.5 per cent Difco Dehydrated Nutrient Agar) and kept as stock cultures, for further study.

Study of morphology

Slides were made from these cultures and stained, first by Gram's method, as modified by Sterling [Hiss and Zinsser (29, p. 103)]. When this staining did not show the form clearly, Loeffler's methylene blue, or Ziehl's carbol fuchsin, was used. On account of pressure of work, the motility of the forms escaped attention until many had died.

Culture reactions

Glucose gelatin. Glucose gelatin was made by adding 10 gm. of glucose and 0.5 cc. each of a 1.6 per cent solution of brom-cresol-purple and cresol-red to a liter of gelatin, made from Difco Dehydrated Nutrient Gelatin. This formula is that suggested by the Committee of the Society of American Bacteriologists (42, p. A 10). With this medium the reaction of the bacteria to glucose and their ability to digest gelatin, and, in the case of the non-liquefiers, their relation to oxygen, could be observed.

Sucrose broth. Sucrose broth was made by adding sucrose and indicators, as in the case of glucose gelatin, to Difco Dehydrated Nutrient Broth, and tubing it in Dunham's fermentation tubes.

Purple milk. Purple milk, made from Difco Dehydrated Purple Milk, was used to test fermentation of lactose, production of rennin, and digestion of casein.

Nitrate broth. Nitrate broth was made by adding 0.02 per cent potassium nitrate to Difco Dehydrated Nutrient Broth. Griess' sulfanilic acid test, given by Fred (23) was used for testing the presence of nitrites.

EXPERIMENTS AND RESULTS

Study of the soil

Situation. The place selected for the collection of the soil was upon the southeast bank of Pantana Wash, at the left of the bridge by which the Tanque Verde Road crosses the wash, a short distance from Tucson. The situation was on top of the high bank and, although in time of flood the wash contains

[3] Through the courtesy of Mr. Godfrey Sykes.

water, the author was assured that the place selected had probably had no water on it, except rain, for at least four years. (See plate 1.) In this connection the following data regarding the annual rainfall were given in an article by MacDougal (41) and supplemented by information from the Desert Laboratory.

Rainfall at the Desert Laboratory

	inches
1918	10.37
1919	19.66
1920	10.51
1921	15.93
1922	10.53
1923	12.61
Average	13.27

This, according to Lipman (38) would be classified as a "truly arid soil." The surface was bare, except for scattered shrubs (see plate 2) and the soil was quite dry and moving with the wind. The collection was made on April 18, 1923.

TABLE 1

Water content of soil

DEPTH	WEIGHT			WATER
	At start	After drying	Loss	
inches	*gm.*	*gm.*	*gm.*	*per cent of dry soil*
6	200	198.10	1.90	0.95
12	200	194.70	5.30	2.65
24	200	195.15	4.85	2.43

TABLE 2

Water capacity of soil

DEPTH	AMOUNTS USED		PERCOLATED WATER	RETAINED WATER	WATER
	Soil	Water			
inches	*gm.*	*cc.*	*cc.*	*cc.*	*per cent of dry soil*
6	10 00	10	7.2	2 80	28
12	8 75	10	7.8	2.20	25
24	10 00	10	7.0	3 00	30

TABLE 3

Combustible material in the soil

DEPTH	BEFORE BURNING	AFTER BURNING	TOTAL LOSS	LOSS OF PLATE	LOSS OF SOIL	WATER
inches	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*per cent of dry soil*
6	50	49.2	0.8	0.1	0.7	1.4
12	50	48.7	1.3	0 2	1.1	2.2
24	50	46.0	4.0	3.0	1.0	2.0

Water content. The water content, tested April 18 and 19, 1923, is shown in table 1.

Water capacity. The water capacity, tested March 25, 1925, is shown in table 2.

Combustible material. The amount of combustible material, determined June 16, 1924, is shown in table 3.

Size of soil particles. Table 4 shows the sizes of soil particles in 100 gm. of dry soil tested on June 16, 1924.

TABLE 4

Various sized particles in 100 gm. of dry soil

DEPTH	>2 MM.	1–2 MM.	0.5–1 MM.	TOTAL	0.124–0.5 MM.	<0.124 MM.	TOTAL
inches	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
6	0.05	0.20	3.40	3.65	56.70	39.70	96.40
12	0.60	1.20	4.40	6.20	38.20	55.40	93.60
24	0.05	0.50	2.30	2.85	40.10	57.10	97.20

TABLE 5

Summary of the physical characters of the soil

DEPTH	WATER CONTENT	WATER CAPACITY	PARTICLES BELOW 0 5 MM.	COMBUSTIBLE MATERIAL	RELATIVE WATER CONTENT*	OPTIMUM WATER CONTENT†
inches	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
6	0.95	28	96.4	1.4	3.4	19.6
12	2.65	25	93.6	2.2	10.4	17.5
24	2.43 .	30	97.2	2.0	8.1	21.0

* By relative water content is meant the ratio $\frac{\text{water content}}{\text{water capacity}}$.

† Optimum water content is taken to be 70 per cent of capacity.

TABLE 6

Hydrogen-ion concentration of the soil

DEPTH	THYMOL BLUE	CRESOL RED
inches	*pH*	*pH*
6	9.0	8.8
12	8.6	8.6
24	8.8	9.0

From the comparison given in table 5 it appears that, although the differences are slight, at 12 inches this particular soil is a little coarser than at 6 or 24 inches, with a correspondingly lower water capacity. It also contains a little more combustible material and has a little higher actual and relative water content.

Reaction of the soil. The hydrogen-ion concentration of the soil, tested February 28, 1925, is shown in table 6.

As this was so close to the range limit of Cresol red, the experiment was again repeated, this time with Thymol blue. This second test agreed exactly with the first one made with this indicator and was accepted as correct.

Water-soluble salts. The analysis was made in June, 1925, two years after the soil was collected. As the soil had been kept perfectly dry and tightly closed, probably the only change which might have taken place is a loss of carbon dioxide, which would probably have been lost in equal amount, if at all, from all three samples. The figures given in table 7 are the results of duplicate tests, which were either identical or checked rather closely. In the latter case the average is given. The percentages are for dry soil.

TABLE 7

Water-soluble salts in the soil

DEPTH	TOTAL SALTS	Cl	CO_3	SO_4	OTHER SALTS
inches	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
6	0.0595	0.0070	0.0090	0.001±	0.0505
12	0.0732	0.0151	0.0204	0.0018	0.0359
24	0.0284	0.0070	0.0087	Trace	0.0197

TABLE 8

Average numbers of organisms per gram of fresh soil

DEPTH	DILUTION*	NUMBER OF PLATES	AFTER 6 DAYS	AFTER 10 DAYS	AVERAGE 10 DAYS
inches					
6	1:10,000	6	238,000	352,000	
	1:100,000	6	320,000	450,000	401,000
12	1:10,000	3	1,560,000	1,930,000	
	1:100,000	6	1,367,000	1,867,000	1,898,500
24	1:10,000	6	425,000	783,000	
	1:100,000	6	650,000	1,050,000	916,500

* The number of colonies was so small on the 1:1,000,000 dilution plates that the count was not considered.

The figures under "other salts" in table 7 were obtained by subtraction from total salts and, therefore, contain the various cations of the anions given, plus the nitrates and traces of anything else soluble. If the cations were eliminated the 12-inch sample would be reduced more than the 6-inch or 24-inch samples, and this would make the difference in the nitrate content still greater.

As the 12-inch layer, although containing the most carbonates, has the lowest hydroxyl-ion concentration, it would seem that the carbonate cannot be the sodium salt, since, according to Atkins (3) very little of this salt is needed to raise the alkalinity to pH 10. He considers that the hydrogen-ion concentration is dynamic, that it varies with temperature, water content and other factors, and that it is a waste of time to try to measure it with great care and accuracy.

The numbers of organisms in the soil

The results shown in table 8 take into consideration only the fungi, actinomycetes, yeasts, and bacteria which grow under the conditions of the experiment. The plates were poured on April 20, 1923 and were counted after 6 and 10 days incubation at room temperature.

The numbers in table 8 were calculated per gram of fresh soil, according to the method proposed by Waksman (55). Reduced to number per gram of dry soil the figures become, for 6 inches 405,050 per gm.; for 12 inches, 1,957,216 per gm.; and for 24 inches, 935,204 per gm.

One set of plates for each depth was selected as showing the most varied assortment of colonies. A count was made and recorded in table 9. In this table and in subsequent discussions "bacteria" is used to indicate the lower forms and does not include the actinomycetes.

TABLE 9

The numbers of colonies of various forms found on plates

DEPTH	DILUTION	NUMBER OF PLATES	TOTAL NUMBER	ACTINOMYCETES		FUNGI		YEASTS, BACTERIA	
inches					*per cent*		*per cent*		*per cent*
6	1:10,000	6	200	97	48.50	1	0.50	102	51.00
12	1:100,000	5	99	47	47.47	1	1.01	51	51.51
24	1:10,000	6	470	259	55 01	4	0.85	207	44.04
All.		17	769	403	52 40	6	0.77	306	46.81

TABLE 10

Colored bacteria, or yeasts, on the plates

DEPTH	TOTAL NUMBER OF COLONIES	WHITE	YELLOW	ORANGE	RED	FLUORESCENT	BROWN
inches		*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
6	102	85.29	7.84	0.98	1.96	0.98	2.94
12	51	90 19	5.88	0.00	0 00	0.00	3.92
24	207	89.37	5.79	0 00	0.96	1.93	1.93
All.	360	88.33	6 39	0.28	1.11	1 39	2.50

Considering those colonies without the recognizable character of fungi or actinomycetes, as bacteria or yeasts, a count was made of the various colors appearing on the plates. The results are shown in table 10.

As is usual, white forms predominate, but the striking point in the above table is the general scarcity of colored forms on plates which had been selected for the greatest variation in forms.

It should be noted, in regard to the counts given in tables 9 and 10, that some of the colonies classified as bacteria, or yeasts, may have been actinomycetes in an early stage of development, before their characteristic appearance was evi-

dent. That this is probably true is shown by the fact that some of the colonies that were streaked for stock cultures, proved later to be actinomycetes. In this connection it is interesting to consider the relative numbers of actinomycetes, bacteria, and yeasts, and the distribution of colors in the stock cultures as shown in tables 11 and 12. It will be understood that, in fishing colonies for pure cultures, the effort was made to secure as many different kinds as possible, hence the proportions of colored forms do not agree with those found in plate counts, where many colonies were of the same kind.

TABLE 11

Numbers of various forms fished for pure cultures

DEPTH	TOTAL NUMBER	ACTINOMYCETES	YEASTS	BACTERIA	UNDETERMINED*
inches					
6	26	2	1	21	2
12	27	3	1	20	3
24	35	1	4	13	17
All.........	88	6	6	54	22

* These cultures died before their morphology was studied.

TABLE 12

Distribution of color in forms fished for pure cultures

DEPTH	TOTAL NUMBER*	WHITE, GREY OR CREAM		YELLOW OR ORANGE		RED OR PINK		BROWN	
inches			*per cent*		*per cent*		*per cent*		*per cent*
6	24	18	75.0	5	20.8	1	4.2	0	0
12	26	20	76.9	5	19.2	1	3.8	0	0
24	23	13	56.5	8	34.8	1	4.3	1	4.3
All....	73	51	69.9	18	24 7	3	4 1	1	1.4

* Some of the streaks did not grow, and no color could be determined

The study of pure cultures

The original cultures isolated in 1923 were transferred at intervals and careful observations were made to insure, as far as possible, purity of cultures and healthy growth. The total number of forms under observation was 88. Cultures died out as time went on, others were lost by contamination, in others two forms were separated, and still others proved, upon study, to be actinomycetes or yeasts and were not carried further. At the end of the work 38 were growing normally, 38 had died out or been lost by contamination, 6 were classified as yeasts and 6 as actinomycetes. In tables 11 and 12 may be seen the numbers of the various forms and the distribution of colors in the bacteria and yeasts.

Morphology. Cultures 10 days old were stained by Gram's method and studied. Interpretation was difficult in some cases and more slides were made

at intervals, during the course of the work, and stained in various ways. Table 13 is a summary of the results.

From table 13 it will be seen that a little over a half (57.4 per cent) were non-spore-bearing forms, whereas 42.6 per cent formed spores. About half of the spore-formers were Gram-positive, and made up the bulk of those taking this stain; 10 out of 13 coccus (or coccoid) forms, 8 out of 11 short rods and 5 out of 7 non-spore-bearing long rods were Gram-negative.

Culture reactions. All culture reactions were run in duplicate and repeated whenever the two tubes did not agree. A summary of the production of acid

TABLE 13

Summary of the morphology of bacteria in pure cultures

DEPTH	TOTAL NUMBER	COCCUS OR COCCOID	SMALL RODS	LONG RODS		GRAM'S STAIN	
				Spores	None	Negative	Positive
inches		*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
6	21	33.30	23.80	33 30	9.50	81.00	19.00
12	20	15.00	15.00	55.00	15.00	50.00	50.00
24	13	23.10	23.10	38.40	15.40	61.50	38.50
All......	54	24.10	20 40	42.60	12 9	64.80	35 20

TABLE 14

Summary of culture reactions at the end of 2 weeks

DEPTH	BACTERIA CAUSING ACID FERMENTATION OF SUGARS						BACTERIA DIGESTING				BACTERIA REDUCING NITRATES TO NITRITES	
	Glucose		Sucrose		Lactose		Gelatin		Casein			
inches		*per cent*		*per cent*		*per cent*		*per cent*		*per cent*		*per cent*
6	5	25.0	1	5.6	0	0	14	70.0	9	50.0	5	27.8
12	9	47.4	8	47.1	0	0	13	72.2	13	76.4	8	47.1
24	4	33.3	4	36.4	1?	9.0?	10	71.4	4	36.4	2	18.2
All.....	18	35 3	13	28 3	1?	2.20?	37	72 5	26	56.5	15	32.6

in sugars, the digestion of gelatin and casein and the reduction of nitrates, after 2 weeks incubation at room temperature, is given in table 14.

a. Glucose gelatin was inoculated on January 5, 1924, and observed after 2, 4, 7 and 14 days. No gas was observed at any time.

b. Dunham's fermentation tubes of *sucrose broth* were inoculated on July 8 and 16, 1924, and observed after 2, 4, 8 and 15 days. No gas was observed at any time.

c. Purple milk was inoculated on July 16, 1924, and observed after 2, 7 and 14 days. The forms acted upon lactose more slowly than upon glucose or sucrose and there was no observable change in 2 days. There was no coagulation at any time.

d. Nitrate broth was inoculated on July 16, 1924, and tested for nitrites at the end of 1 and 2 weeks.

Of the liquefiers 22 showed distinct liquefaction on the fourth day and 15 in one to two weeks. It was not found possible to group the forms into all the

types suggested by Conn (13, 15, 19). The actinomycetes formed a clearly defined group. The cocci, none of which fermented sugars were about evenly divided among rapid, slow, and non-liquefiers. The proportion of rapid to slow to non-liquefiers in the small rods and coccoid forms was 6:3:6; in the long spore-bearing rods, 12:4:7; and in the long non-spore-bearing rods, 2:4:1.

From table 14 it appears that bacteria living at 12 inches from the surface in this soil are, in general, more active in their chemical processes than those living at 6 or 24 inches, since the largest percentages of acid formers, of casein and gelatin digesters, and of nitrate reducers were found at this depth.

It is to be regretted that so many forms died during the process of the work, which was unavoidably extended over 2 years. Had it been possible to concentrate the work the numbers would have been larger and the results more convincing.

DISCUSSION

Although the significance of this work can be brought out only after the data for other regions are complete, it is advisable to bring together in brief form the results obtained for this type of soil in comparison with those obtained by other investigators.

A review of the literature relating to bacterial counts at various depths, brings out a rather uniformly consistent opinion that the greatest number is in the upper 6 to 8 inches, regardless of the character of the soil studied (5, 10, 28, 39, 53, 54). In a number of instances (8, 5, 32, 53) 4 inches gave the maximum count. From this upper layer of great abundance the numbers in general, decrease with depth. Fränkel (22) is sometimes quoted as having found the highest number at ½ meter. A careful study of his tables, however, shows that the majority of them give no data between the surface and ½ meter. Those instances, therefore, in which the maximum number was at this point, have no significance except that the maximum was not at the surface, as it was in a large proportion of cases. Reimers (47) also used, in general, 1-meter and ½-meter intervals, and his "surface" seems to refer to the whole layer of loose surface soil, which varied considerably in thickness.

In the Tucson soil, of the three layers studied, the largest number of bacteria occurred in the 12 inch stratum, the next largest in the 24 inch layer, and the smallest number at 6 inches from the surface. At 12 inches the average number was 1,957,216 per gram of dry soil and at 24 inches 935,204. A comparison of these figures with the results of Chester (10)—75,000 to 124,000 at 12 inches and 4,000 at 24 inches—suggests that in arid soil the whole curve representing numbers to depth, shifts downward. The fact that bacteria penetrate to greater depths in arid soils than in those of humid regions, is discussed by Lipman in several articles (37, 38, 39).

The work of Cutler, et al. (20) indicates that there are two maxima for the bacterial count in the year, one at the end of June and the other at the end of November. If this be true for all regions, the soil was collected at Tucson

about half way between a maximum and a minimum, and should, therefore, be a fair average. As daily platings were not made, the fluctuations described by Cutler were not noted, or taken into account.

In considering the factors which might be responsible for the distribution of bacteria in the Tucson soil, the most obvious is lack of water. As has been indicated, the average annual rainfall for the year in which the collection was made, and for the five years previous was 13.27 inches. This, combined with the data in tables 1 and 2, shows that the soil is exceedingly dry.

The effect of moisture upon the numbers of bacteria in soil has been considered by a number of investigators. The problem of the bacterial count in arid soil, however, involves more than a consideration of the effect of soil moisture upon the number of bacteria in experimental pots. Pot cultures, to which certain amounts of water are added, or which are allowed to dry out, cannot duplicate exactly the conditions in the field. That drying out of such soil should give a decrease in the number of bacteria, seems reasonable (46), but the work of Waksman (53) indicates that the variation in number does not always agree with the variations in moisture content. There is also considerable disagreement in the numbers of bacteria in soil sampled in the open. Sampling under various conditions led Waksman (56) to conclude that a long dry spell decreases the number of bacteria, whereas a wet spell increases it. Prescott (45) found a decrease in number of bacteria in Egyptian soil after the summer fallow period, during which the soil bakes. Cutler, et al. (20), on the other hand, found, by daily platings, that there were great and unaccountable variations in the numbers, which did not coincide with variations in soil moisture, rainfall, soil temperature, nor seasonal temperature. This great variation is confirmed by Engberding (21), whose curves of bacterial counts show great irregularities, but the greater peaks and hollows of which agree roughly with the curve of monthly precipitation. Russell (49) also noted the same phenomenon of great and irregular variation, but attributed it to variations in protozoal content. It is quite conceivable that a bacterial flora adapted to moist conditions might be much more sensitive to variations in soil moisture than one which had adapted itself to dry conditions. A careful study of this problem would probably yield interesting results.

Although the soil at Tucson was loose and sandy in appearance, a rough analysis showed that a large proportion was of fine material, a characteristic which will probably be of importance in future comparisons. Notwithstanding this fine character, the water capacity was low, partly, no doubt, because of the small amount of organic material. The reaction of the soil was very alkaline (pH 8.6 to 9) and the upper layer had the highest pH value. This test was made about two years after the collection of the samples, which had, nevertheless, been kept tightly closed and dry during the interval. According to several observers (1, 7, 48), soil, especially that on the alkaline side of neutrality, becomes more acid upon storage and drying. The results submitted in table 6, therefore, are probably more acid than they would have been

with fresh soil. Arrhenius (1) states that 14 days standing has no effect upon the reaction, but he cautions against long storage. The data for wind-blown soils have been gathered from coastal dunes, and will be discussed in the second part of the work.

Stewart (52) has made many chemical analyses of Utah soils, some with, and others without, "alkali." By comparing his tables with table 7 many interesting points may be noted. Except for certain "surface" collections, his first sample was taken at a depth of 12 inches, and the others at 1-foot intervals. In his tables the percentages are given for definite salts rather than for the atomic groups as in the analysis of the Tucson soil, consequently only approximate comparisons can be made. In all his analyses, except for one surface—non-alkali—soil, the percentages of total salts are much higher than in the Tucson soil, and since the chlorides, carbonates, and nitrates are fairly comparable, the difference lies chiefly in the sulfate content. The percentages of total salts and of individual salts, except nitrates, increased downward in the Utah soils, whereas in the Tucson soil the highest percentages of these salts was at 12 inches. The tendency for the nitrates to accumulate in the upper layer agrees with Stewart's analyses.

The fact that the 12 inch layer contained the most soluble salts, except nitrates, and also had the highest bacterial count, suggests that in these concentrations, chlorides, carbonates and sulfates may be stimulating. There has been a considerable amount of work upon the effect of salts upon the development and activities of bacteria, but since the investigators have used different amounts of the salts, different criteria for evidence of effect, and different conditions under which the experiments were conducted, it is exceedingly difficult to correlate the results. Lipman (34) found that Na_2CO_3 stimulated ammonifying bacteria, but that neither NaCl nor Na_2SO_4 had that action. Greaves (26) found that the common soil alkalies, NaCl, $CaCl_2$ Na_2SO_4 and $NaNO_3$ were toxic to these bacteria; that there was no stimulating action in any concentration of NaCl, $Ca(NO_3)_2$, KCl, K_2SO_4, $Mg(NO_3)_2$ or Na_2SO_4, but that the other salts used stimulated this process at some concentration. Fred and Hart (24) report that $CaSO_4$ stimulates ammonification. With respect to nitrifying bacteria, Lipman (35) found that very weak solutions of NaCl and Na_2SO_4 were stimulating, whereas Na_2CO_3 was toxic at the highest dilution used (0.025 per cent). Brown and Hitchcock (6) agree, in general, with this work, but found the toxic points to differ from those of Lipman, and include Na_2CO_3 among the salts stimulating in dilute solutions. For the nitrogen-fixing organisms Lipman (36) found that there was no stimulation by any of the three salts studied, in the dilutions used. Chester (9) found that $NaNO_3$ and KCl used in the proportion of 1 part of salt to 5,000 parts of soil, or 0.02 per cent, were without appreciable effect on the bacterial development in the soil.

In the Tucson soil the dilutions of salts were below the toxic points found by the aforementioned investigators. Using 0.2 *M* concentration, Hohn and

Sherman (30) found that nitrates, as well as chlorides and sulfates, accelerated the growth of *B. coli.* In the 6 inch layer of Tucson soil the amount of nitrates was much less than that used by these investigators, although it was somewhat greater than the amounts in the 12 inch and 24 inch layers. It is possible that this slight excess, associated with other unfavorable conditions, such as relatively low water and organic content and high alkalinity, helped to inhibit the growth of bacteria, whereas the greater porosity, higher water and organic content, lower alkalinity, and higher content of salts with stimulating action, favored the growth of organisms in the 12 inch layer.

According to Hilgard (27) the salts in arid soil are carried down a few feet by the scant water supply, and accumulate there, whence they rise, by capillarity, with the evaporating water. Stewart (52) notes that in some sections, where the soil is well drained, there is a marked lack of salts, because they have been carried down to lower land. This seems to be the probable explanation for the low salt content of the soil at the edge of Pantana Wash, much of the salts having been carried down into the wash by percolating water. The 12 inch layer is probably the stratum in which the descending and ascending waters cause a slight accumulation. Whether the accumulation of nitrates in the 6 inch layer is due to the physico-chemical nature of the salts, or to greater nitrification in that layer, cannot be determined without extended experimentation.

The variation in kinds of bacteria is exceedingly important. No attempt has been made to identify specific organisms, but merely to ascertain the relative proportion of types. Yeasts, actinomycetes, and bacteria have been distinguished and the latter grouped morphologically and according to a limited number of physiological reactions.

It is impossible to give plate counts of yeasts unless every colony is examined, because it is impossible superficially to distinguish them from bacteria. Also it is impossible to know how many of the colonies given in plate counts by other writers were yeasts.

The actinomycetes are more easily distinguished, although in the early stages, and in the case of small, deep colonies, it is impossible to distinguish them from bacteria or yeasts. Lipman and Waynick (40) state that there is a decrease in the number of bacteria when a soil is transferred from a humid to an arid climate, and also a decrease in nitrification and nitrogen-fixation, but not in cellulose destruction. Waksman and Heukelekian (58) have shown that cellulose destruction may be carried on by fungi, actinomycetes, and bacteria. Arid soil appears to be unfavorable to the growth of fungi, hence the cellulose destruction in it must be due predominantly to actinomycetes and bacteria. Since the work of T. L. Martin (43) showed that actinomycetes were affected by the addition of green manure more than were bacteria, it is possible that the actinomycetes are more active in the destruction of cellulose than the lower forms. It is possible, therefore, that the statement of Lipman and Waynick suggests, at least, that there may be more actinomycetes in arid soil than in

other situations. Waksman (53) studied the distribution of fungi, actinomycetes, and bacteria in various soils (textures not given) and concluded that although bacteria decreased downward and fungi almost disappeared below 12 inches, the actinomycetes remained constant between 12 inches and 30 inches, hence they increased in proportion to the other groups in the lower layers. A comparison of table 9 with his results, shows a fairly close agreement in the numbers of fungi and actinomycetes at the deeper layers, but a considerable difference for all counts at 12 inches and for the bacteria at the lower level. At 12 inches the Tucson soil contained 4 to 6 times as many actinomycetes, only one-sixth to one-seventh as many fungi, and about five-eighths as many bacteria as the soils studied by Waksman. Although the work of W. H. Martin (44) upon potato scab showed an increase of the disease in dry alkali soils, Sanford (50) concluded that lack of moisture alone was responsible for the disease. His work was with heavily infected soils, consequently lack of infection did not indicate lack of organisms. The work seems to indicate that dry, and possibly alkaline, soils are favorable for actinomycetes. Conn (14, 18) found that sod contained a larger number of actinomycetes than cultivated soil—38 per cent and 20 per cent, respectively—and thought that the difference was not due to lack of aeration in sod, but possibly to the presence of plant roots. In other reports (12, 19) upon various soils, he gives the percentages of these forms as anywhere from 12 to 50. Hiltner and Störmer (28) give as an example, a plate counting showing over 25 per cent of actinomycetes. Krainsky (33) placed the number of these forms in dune sand between those for sandy woods and beech woods, but gave no figures.

Conn's suggestion, that the function of actinomycetes in the soil is the decomposition of plant roots, does not exclude the disintegration of cellulose. Both functions would imply a correlation between the number of these forms and the quantity of vegetable matter in the soil. On the other hand, the number of actinomycetes is larger in Tucson soil than in any soil reported, except in the general statement by Conn noted above, that they compose 12 to 50 per cent of the soil flora. The percentage for the 24 inch layer exceeds even this estimate by about 5 per cent. (See table 9.) It is, therefore, difficult to account for the high percentage of these organisms in the Arizona soil studied.

That chromogenesis is confined largely to yellow and fluorescent forms (15) is only partly confirmed by the present investigation. In general, there was a great lack of color; even on nutrose agar over 88 per cent of the colonies were white. Although yellow was the most prevalent color, the percentage of yellow colonies was very low. The fact that brown forms were next in abundance is interesting, but its significance is not known. Red, orange, and fluorescent forms were scarce and no purple, blue, or black forms were found.

In several publications Conn (12, 13, 15, 16, 17) discussed the types of bacteria in soils, and in 1917 (19) he summarized his previous work and classified the types into several groups. Of these the non-spore-bearing forms are the

most abundant, and the spore-bearers few and unimportant. The percentage of the latter group is given as 5 to 10. Of the non-spore-formers, he found rapidly liquefying short rods of the *Pseudomonas fluorescens* type to be less than 10 per cent, and short rods or cocci, slow or non-liquefiers, which do not ferment sugars, to be from 40 to 75 per cent. Many of these grow poorly on laboratory media. He noted the absence, or presence in such small numbers as to be overlooked, of forms that ferment sugars with gas, of non-liquefying acid formers, and of non-spore-bearers growing anaerobically in sugar broths. No mention is made of the reaction to Gram's stain. Skinner (51) also found aerobic spore-formers to be about 5 to 10 per cent of the total count in various soils.

A consideration of table 13 will show a totally different distribution of types in the Arizona soil from those discussed above. Of the cultures studied morphologically, 57.4 per cent were non-spore-bearing, and of these, about 58 per cent were rods. The forms were distributed rather unevenly in the three layers. The cocci were most abundant in the upper layer, and least at 12 inches. The spore-formers were most abundant at 12 inches, and least at 6 inches. The short rods were least abundant at 12 inches, and in about equal numbers at 6 inches and 24 inches. The non-spore-forming long rods were least abundant at 6 inches, and about equally abundant at 12 inches and 24 inches. Gram negative forms predominated, especially at 6 inches (81 per cent). At 12 inches the forms were evenly divided between positives and negatives, and at 24 inches there were about twice as many negatives as positives. At 12 inches were found the largest percentages of acid formers, gelatin and casein digesters, and nitrate reducers. That this is not due wholly to the spore-formers is shown by the fact that about 50 per cent of the digestion of gelatin and casein was due to other forms. At this depth the spore-formers, however, are the active sugar fermenters and nitrate reducers.

The total lack of gas in sugar fermentation, and the probable total lack[4] of lactose fermenters, agrees with the results of Conn, noted above. Approxima tely 35 per cent of the total number of forms studied formed acid in glucose, ands28 per cent in sucrose. The fact that one-third of the glucose and 2 of the sucroye fermenters were non-liquefiers, is at variance with his findings. Approximatela 57 pe r cent of the forms studied digested casein, 72.5 per cent digested gelatin, and 33 per cent reduced nitrates. Of the liquefiers, about 60 per cent were rapid, i.e., produced a fair amount of liquefaction in 4 days. The digestion of gelatin was the most active process carried on by the organisms studied. Protein digestion presupposes organic matter and it is difficult to account for such active digesters in soil with so small an amount of organic material. On the other hand, this activity would insure that the small amount of such material would quickly and efficiently be made available.

[4] The single form that caused a slightly acid reaction in milk may have been a contamination, or it may have been one of the "few" which Conn did not find.

SUMMARY

1. In this study only those bacteria are considered which grow aerobically on ordinary culture media.

2. The soil under consideration was collected at depths of 6 inches, 12 inches and 24 inches, on the edge of Pantana wash at the side of the Tanque Verde Road, Tucson, Arizona.

3. The average annual rainfall for 6 years, including the one in which the soil was collected, was 13.27 inches. This would make it, according to Lipman, a "truly arid soil."

4. The 12-inch layer had the greatest water content, both in actual amount and in relation to the water capacity. It was a little coarser, and had a larger amount of combustible material, and of soluble chlorides, carbonates and sulfates, than the other layers. It was more nearly neutral (pH 8.6) than the other samples. These characteristics were correlated with the highest bacterial count.

5. That the 6-inch layer was the least favorable for bacteria, was shown by the lowest count, and was probably due to the fact that this layer was the driest and had the least combustible material, the highest hydroxyl-ion concentration (pH 9.0), and the largest amount of nitrates of the three.

6. The numbers of bacteria per gram of fresh soil for the depths were as follows: 6 inches, 401,000; 12 inches, 1,898,500; 24 inches, 916,500.

7. Of the total number of colonies for all depths, 52.4 per cent were actinomycetes, 0.77 per cent were filamentous fungi and 46.81 per cent were yeasts and bacteria. The actinomycetes were actually and proportionally more numerous at 24 inches than at 6 or 12 inches.

8. Of the colonies which were not recognized as actinomycetes, and were therefore classified as bacteria and yeasts, 88.33 per cent were white; 6.39 per cent, yellow; 0.28 per cent, orange; 1.11 per cent, red; 1.39 per cent, fluorescent; and 2.5 per cent, brown.

9. Pure cultures were isolated from the plates and studied morphologically and culturally.

10. Morphologically, 24.1 per cent were coccus, or coccoid, 20.4 per cent were short, non-spore-bearing rods, 13.0 per cent were long non-spore-bearing rods, 42.6 per cent were long spore-bearing rods, and 64.8 per cent were Gram negative.

11. Culturally, 35.3 per cent fermented glucose; 28.3 per cent fermented sucrose; and only one form fermented lactose; 70.4 per cent digested gelatin and 56.5 per cent digested casein; 32.6 per cent reduced nitrates to nitrites.

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PLATE 1

FIG. 1. View of the Pantana Wash and the Tanque Verde Bridge. Taken from the bottom of the wash and looking toward the bank on top of which the soil samples were collected.

FIG. 2. Nearer view of the bank.

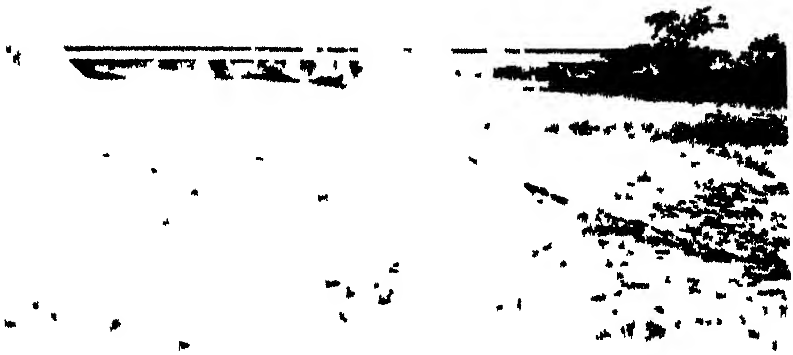

Fig 1

Fig 2

PLATE 2

FIG. 1. General view of the situation in which the soil samples were collected.
FIG. 2. A nearer view of the surface at the place of collection.

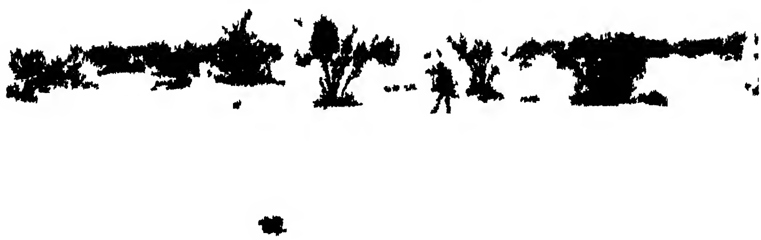

Fig. 1

Fig. 2

THE USE OF THE QUINHYDRONE ELECTRODE FOR MEASURING THE HYDROGEN-ION CONCENTRATION OF SOILS

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HISTORICAL AND THEORETICAL

The electrometric method for determining the hydrogen-ion concentration of soils by means of the ordinary hydrogen electrode has never been entirely satisfactory. This is due to the fact that a constant voltage cannot be quickly and easily obtained. Often hydrogen has to be passed through the soil suspension for a long period of time before constant readings can be secured. In many cases accurate results cannot be obtained. In measuring the hydrogen-ion concentration of neutral or slightly alkaline soils, the carbon dioxide equilibrium enters into the reaction and the observed voltages are often misleading. The electrodes become abraded easily in sandy soils and only a few determinations can be made without replatinizing. Coupled with the difficulty of obtaining a constant potential, the care of the electrodes makes the method not only complicated and tedious but also very slow.

The colorimetric method has a limited application. It is satisfactory with clear soil extracts, but precise readings cannot be made with turbid suspensions The method requires the use of a series of indicators and buffer mixtures which are likely to change with time and give inaccurate results.

In 1920, Biilmann (1, 3) showed that it was possible to form with the organic compound, quinhydrone, an electrode which could be used for making hydrogen-ion determinations and with which very constant voltages were possible. The quinhydrone molecule is apparently formed by the union of one molecule of quinone, $C_6H_4O_2$, and one of hydroquinone, $C_6H_4O_2H_2$. In an aqueous solution it is very highly dissociated into its components.

Hydroquinone and quinone, the products of the dissociation of the quinhydrone, are the active bodies of the electrode. According to the equlibrium equation,

$$C_6H_4O_2H_2 \rightleftharpoons C_6H_4O_2 + H_2$$

the concentration of hydrogen is represented by the formula:

$$(H_2) = \frac{(C_6H_4O_2H_2)}{(C_6H_4O_2)} \cdot K \tag{A}$$

[1] The writer expresses his appreciation for the helpful suggestions from Professors G. W. Conrey and R. M. Salter.

where K is a constant. The concentration of hydrogen at a given temperature, therefore, is "entirely determined by the proportion between the molecular concentration of the hydroquinone and the molecular concentration of the quinone, but which does not depend on the absolute concentrations of these bodies nor on the concentration of the hydrogen ions in solution."

Biilmann used an element composed of two electrodes: one, a platinum foil dipped into a solution of quinhydrone in decinormal hydrochloric acid and the other, the usual hydrogen electrode immersed in the same acid. This element is represented as:

$$\text{Pt.} \mid C_6H_4O_2,\ C_6H_4O_2H_2,\ N/10\ \text{HCl} \mid N/10\ \text{HCl},\ H_2 \mid \text{Pt.}$$

The quinhydrone electrode is positive in respect to the hydrogen electrode.

At 18°C. he obtained a potential of 0.7044 volt using dry hydrogen under a pressure of one atmosphere. To transfer the voltage into conditions where humid hydrogen is used, 0.0002 volt must be subtracted from this value. The Sorensen formula for pH at 18°C. for a decinormal calomel electrode is

$$\text{pH} = \frac{E - 0.3377}{0.0577} \qquad \text{(B)}$$

in which E represents the observed voltage. By substituting $0.7042 - Eq$ for E in equation B, the formula for pH at 18°C. for the quinhydrone electrode is derived

$$\text{pH} = \frac{0.3665 - Eq}{0.0577} \qquad \text{(C)}$$

Eq is the observed voltage for the quinhydrone electrode.

In 1923, Biilmann (2) showed that this electrode was applicable in determining the hydrogen-ion concentration of soils. When it was compared with the ordinary hydrogen electrode good checks were secured. Up to the present time no standardization of methods for using this electrode has been published. It is the purpose of this paper to report certain studies which have been made of the factors which enter into the use of the quinhydrone electrode for measuring the reaction of soils. Consideration was given to the use of the saturated, normal, and decinormal calomel cells; to variation in the amount of quinhydrone; to measuring the constancy of potential; to comparing the quinhydrone and hydrogen electrodes; and to the effect of the soil-water ratio upon results secured with the quinhydrone electrode.

PROCEDURE

A test tube with a diameter of 2 cc. and a depth of 14 cc. was employed for holding the soil suspension and the quinhydrone. Into this was placed a platinum electrode, which was made by fusing a platinum foil 12 mm. square onto a stiff platinum wire that had been previously fused in the end of a Pyrex

glass tube. This composed the quinhydrone electrode. It was connected to the calomel cell by a saturated KCl agar bridge. The agar bridge was renewed whenever it exhibited signs of deterioration, which was indicated by cracks in the agar and by erratic voltages. Since the completion of this work, Schollenberger (6) has constructed a cell which eliminates the agar bridge. The care of the platinum electrode is a very important factor in this method. At the beginning of each day's work, the electrode was cleaned in a hot chromic acid solution, washed thoroughly with freshly boiled distilled water, and heated to redness in an alcohol flame. An ordinary gas flame cannot be used. After readings were made, the test tube containing the soil suspension-quinhydrone mixture was removed and the platinum electrode and agar bridge were thoroughly rinsed with distilled water. The cell was immersed in water of a known temperature while the readings were made and the appropriate temperature correction applied in each case. A Leeds and Northrup Type K Potentiometer and Type R galvanometer were used to measure the observed voltages.

EXPERIMENTAL

The use of saturated, normal, and decinormal calomel cells

Biilmann experimented with a decinormal electrode, with which the observed voltage is 0.7042. From this the formula for the hydrogen-ion concentration is derived as expressed in equation C. This is a direct substitution of his results in the equation derived from the Nernst formula,

$$E = E_0 - \frac{RT}{nF} \times 2.303 \log C \tag{D}$$

in which E = electrode potential corresponding to ionic concentration C,
E_0 = electrolytic potential (electrode potential at molar concentration),
R = the gas constant (8.32 joules per degree),
T = absolute temperature (273° + temperature C),
n = Valency of the ion,
F = the faraday (96,500 coulombs)
C = ionic concentration of the solution.

The value of $\frac{RT}{nF} \times 2.303$ at 18° and 25°C. is 0.0577 and 0.0591, respectively.

From these values, using Biilmann's method of obtaining equation C and and the voltage 0.6988 as measured for the decinormal electrode at 25°C., the formula for the hydrogen-ion concentration as expressed in pH can be derived.

$$\begin{aligned} E &= E_0 - 0.0591\ \text{pH} \\ 0.6988 - Eq &= 0.336 - 0.0591\ \text{pH} \\ \text{pH} &= \frac{0.3628 - Eq}{0.0591} \end{aligned} \tag{E}$$

In addition to the decinormal electrode both the normal and the saturated were used. For the normal electrode, using the same method of calculation as in equation E and the value 0.283 for E_0, the following equation is obtained:

$$\mathrm{pH} = \frac{0.4158 - Eq}{0.0591} \tag{F}$$

For the saturated electrode, E_0 is 0.245 and the resulting equation is

$$\mathrm{pH} = \frac{0.4538 - Eq}{0.0591} \tag{G}$$

The temperature factor as determined in Biilmann's investigations is 0.77 millivolt per degree deviation from 25°C. Below this temperature the correction must be subtracted from *Eq;* above 25° it must be added. A comparison of results secured with the three electrodes is shown in table 1.

These results indicate that any one of the three calomel cells may be used. The saturated electrode, however, is preferred for convenience. In the first

TABLE 1

A comparison of pH values for the saturated, normal and decinormal calomel cells

NUMBER	SOIL TYPE	CALOMEL ELECTRODE		
		Saturated	Normal	Decinormal
30	Trumbull silt loam	4.63	4.65	4.67
6	Paulding clay	6.38	6.36	6.33
130	Dunkirk fine sand	5.22	5 22	5.20

place, it is more constant. The normalities of the normal and decinormal cells change more quickly than the saturated. Secondly, in soils that are neutral or slightly alkaline a negative potential is obtained at a lower pH with the normal and decinormal. For the saturated electrode, a negative voltage is produced at pH 7.68; for the normal, at 7.02; and for the decinormal, at 6.14. When a negative potential is obtained, the poles must be reversed. The saturated cell does not often require this reversal since most soils have a hydrogen-ion concentration lower than pH 7.68.

The effect of varying the amounts of quinhydrone

The weight of quinhydrone necessary to give a constant voltage in Biilmann's experiments was 0.1 gm. for every 15 cc. of solution. However, the results in table 2 indicate that 0.05 gm. suffices for accurate results. In acid soils 0.02 gm. is sufficient. Quinhydrone added in excess of 0.05 gm. did not produce further change.

A convenient method of adding the quinhydrone to the soil suspension is by using a small glass spoon, blown on the end of a glass tube. The spoon

holds about 0.05 gm. If a large number of determinations are to be made at one time, the process of measuring the quinhydrone for each determination can be eliminated by making a fresh 0.3 per cent solution of quinhydrone with boiled distilled water and by adding the resulting solution to the soil. This solution must be kept in a dark bottle because light tends to dissociate the quinhydrone. The solution cannot be used on the second day because of this dissociation. The results in table 3 show the relation between the addition of quinhydrone in solution and in the dry state directly to the soil suspension.

TABLE 2

Effect of varying the amounts of quinhydrone upon the observed pH of the soil suspension

NUMBER	SOIL TYPE	AMOUNTS OF QUINHYDRONE PER 15 CC. OF H_2O ADDED TO 15 GM. OF SOIL				
		0.01 gm.	0.02 gm.	0.03 gm.	0.04 gm.	0.05 gm.
		pH	*pH*	*pH*	*pH*	*pH*
41	Tyler silt loam	4.10	4.18	4.19	4.18	4.19
507	Cory silt loam	4.54	4.81	4.85	4.84	4.86
22	Wooster silt loam	6.81	7.04	7.11	7.22	7.22

TABLE 3

The pH values from two methods of adding quinhydrone

NUMBER	SOIL TYPE	METHOD OF ADDING QUINHYDRONE	
		Directly to the soil suspension	In solution
22	Wooster silt loam	7.11	7.06
507 A	Cory silt loam	4.88	4.84
507 B	Cory silt loam	5.06	5.08
518	Cincinnati silt loam	5.55	5.50
41	Tyler silt loam	4.25	4.26

Measuring the Constancy of Potential

It is often difficult to obtain a constant voltage when using the ordinary hydrogen electrode. This difficulty is not so great with the quinhydrone method. With most soils the latter gives very constant readings and equilibrium is quickly reached. With alkaline soils, however, the voltage is not exactly constant and the readings must be taken immediately after adding the quinhydrone to the soil suspension. La Mer and Parsons (4), studying the application of the quinhydrone electrode to electrometric titrations, found that a constant voltage could not be reached in an alkaline solution with a pH above 8.0 They attributed this to the autoxidation of the hydroquinone. In measuring the hydrogen-ion concentration of soils, this factor is not of large significance because few soils with the exception of the alkali

TABLE 4

Measuring the constancy of potential for the quinhydrone electrode

NUMBER	SOIL TYPE	TIME OF MAKING READINGS									
		Instantly		1 minute		3 minutes		5 minutes		10 minutes	
		volts	*pH*	*volts*	*pH*	*volts*	*pH*	*volts*	*pH*	*volts*	*pH*
30	Trumbull silt loam	0.1775	4.67	0.1775	4.67	0.1751	4.71	0.1751	4.71	0.1797	4.64
130	Dunkirk fine sand	0.1490	5.16	0.1475	5.18	0.1475	5.18	0.1467	5.20	0.1471	5.19
6	Paulding clay	0.0775	6.33	0.0781	6.34	0.0781	6.34	0.0781	6.34	0.0781	6.34
327	Newton fine sandy loam	0.0128	7.47	0.0133	7.46	0.0148	7.44	0.0158	7.42	0.0163	7.41
523	Genesee silt loam	−0.0345	8.26	−0.0339	8.25	−0.0290	8.17	−0.0232	8.07	−0.0147	7.93

soils have pH values as high a 8.0. Constant readings with soils below pH 8.0 are readily obtained (table 4).

During a 10-minute interval, the largest deviation of potential, with the exception of soil 523, corresponds to a difference in pH of 0.07. For most purposes this variation has no significance. In the alkaline soil the voltage varied almost 0.10 in pH during 3 minutes and for a 10-minute period reached a deviation of 0.33 in pH from the original reading. If the readings are made immediately, however, excellent checks between duplicate samples can be obtained. Several hundred samples studied with this electrode have given uniformly excellent results.

TABLE 5

Comparison of the quinhydrone and hydrogen electrodes

NUMBER	SOIL TYPE	HYDROGEN ELECTRODE		QUINHYDRONE ELECTRODE	
		volts	*pH*	*volts*	*pH*
6	Paulding clay	0 6215	6 37	0.0800	6.37
30	Trumbull silt loam	0.5025	4 39	0.1788	4.66
41	Tyler silt loam	0 4825	4.02	0.2083	4.16
90	Newton very fine sandy loam	0 5815	5.69	0.1074	5.87
101	Fulton silty clay	0 6185	6.32	0.0720	6.46
130	Dunkirk fine sand	0.5415	5.01	0.1456	5.23
135	Newton loam	0.6035	6.06	0.0935	6.10
153	Clyde silty clay loam	0.5890	5.82	0.1136	5.76
321	Newton clay loam	0.5875	5.79	0.1035	5.93
501	Clermont silt loam	0.5355	4.91	0.1572	5.02
507	Cory silt loam	0.5340	4.89	0.1659	4.88
518	Cincinnati silt loam	0.5675	5.45	0.1240	5.60

A comparison of the quinhydrone and hydrogen electrodes

Biilmann (2) found a variation from 0 to 0.2 in the pH values secured between the quinhydrone and hydrogen electrodes in a series of 75 different soils. Most of the samples checked within 0.1 in pH. This is considered a good check, since a given soil often shows greater variation from time to time. Table 5 gives a comparison of the results secured by the use of the two electrodes in 12 different soils and shows a variation similar in magnitude to Biilmann's work. Only two soils deviate more than 0.2 in pH. The method previously outlined was used to determine the hydrogen-ion concentration of these soils. A soil-water ratio of 1:1 was used for the quinhydrone method and 1:5 for the ordinary hydrogen electrode method.

The ordinary hydrogen electrode gave erratic voltages with soils that were alkaline. The results indicate the reliability of the quinhydrone electrode for measuring the hydrogen-ion concentration of soils.

TABLE 6

Effect of the soil-water ratio on the hydrogen-ion concentration of soils

NUMBER	SOIL TYPE	HYDROGEN-ION CONCENTRATION, Soil-water ratio					pH, Soil-water ratio				
		2:1	1:1	2:3	1:2	2:5	2:1	1:1	2:3	1:2	2:5
6	Paulding clay	6.456×10^{-7}	4.266×10^{-7}	3.548×10^{-7}	3.020×10^{-7}	3.020×10^{-7}	6.19	6.37	6.45	6.52	6.52
30	Trumbull silt loam	2.754×10^{-5}	2.188×10^{-5}	2.089×10^{-5}	1.995×10^{-5}	1.863×10^{-5}	4.56	4.66	4.68	4.70	4.73
90	Newton very fine sandy loam	1.514×10^{-6}	1.349×10^{-6}	1.175×10^{-6}	1.072×10^{-6}	9.55×10^{-7}	5.82	5.87	5.93	5.97	6.02
101	Fulton silty clay	5.012×10^{-7}	3.467×10^{-7}	2.951×10^{-7}	2.570×10^{-7}	2.455×10^{-7}	6.30	6.46	6.53	6.59	6.61
130	Dunkirk fine sand	7.413×10^{-6}	5.888×10^{-6}	5.623×10^{-6}	4.365×10^{-6}		5.13	5.23	5.25	5.36	
135	Newton loam	1.072×10^{-6}	7.943×10^{-7}	6.761×10^{-7}	6.026×10^{-7}	5.623×10^{-7}	5.97	6.10	6.17	6.22	6.25
153	Clyde silty clay loam	2.291×10^{-7}	1.738×10^{-7}	1.413×10^{-7}	1.318×10^{-7}	1.148×10^{-7}	5.64	5.76	5.85	5.88	5.94
321	Newton clay loam	1.660×10^{-6}	1.175×10^{-6}	1.047×10^{-6}	8.913×10^{-7}	7.080×10^{-7}	5.78	5.93	5.98	6.05	6.15
327	Newton fine sandy loam	5.370×10^{-8}	3.715×10^{-8}	3.311×10^{-8}	3.020×10^{-8}	2.692×10^{-8}	7.27	7.43	7.48	7.52	7.57
501	Clermont silt loam	1.202×10^{-5}	9.550×10^{-6}	8.318×10^{-6}	7.413×10^{-6}	6.761×10^{-6}	4.92	5.02	5.08	5.13	5.17
523	Genesee silt loam	7.413×10^{-9}	4.898×10^{-9}	3.467×10^{-9}	3.631×10^{-9}	3.802×10^{-9}	8.13	8.31	8.46	8.44	8.42
528	Crosby silt loam	8.128×10^{-7}	5.370×10^{-7}	4.898×10^{-7}	5.248×10^{-7}	5.495×10^{-7}	6.09	6.27	6.31	6.28	6.26

Effect of the soil-water ratio on the hydrogen-ion concentration

Salter and Morgan (5) having studied the effect of varying the soil-water ratio in determinations of hydrogen-ion concentration of soils by the ordinary hydrogen electrode method, came to the conclusion that a ratio of 1:5 might well be chosen as a standard ratio for such measurements. They pointed out that the variation of the hydrogen-ion concentration with varying

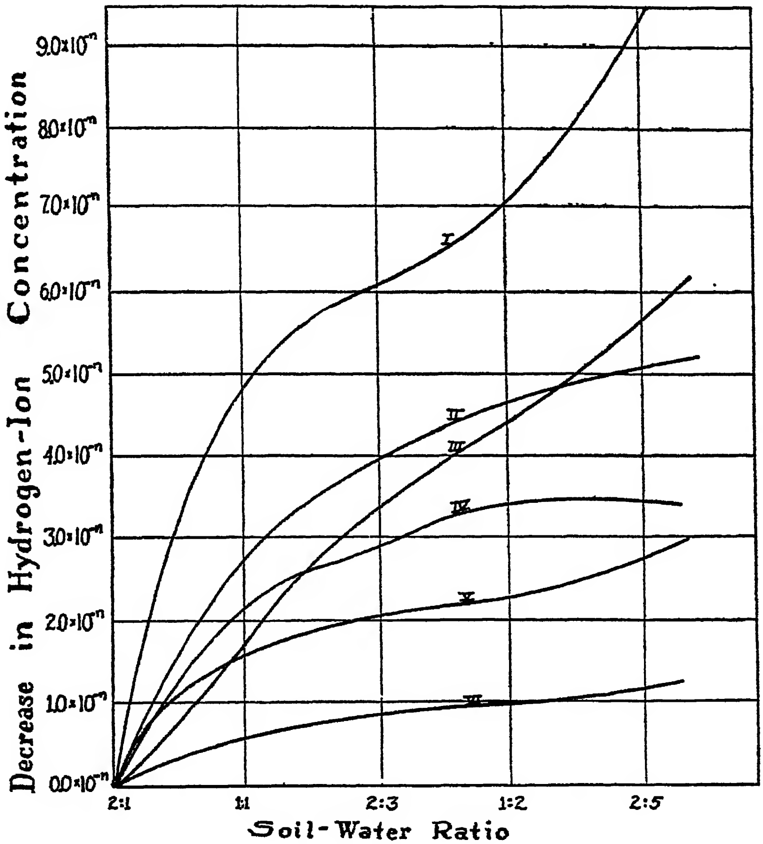

FIG. 1

I = Soil 321. n = 7.
II = Soil 135. n = 7.
III = Soil 90. n = 7.
IV = Soil 6. n = 7.
V = Soil 327. n = 8.
VI = Soil 153. n = 6.

soil-water ratios could be described by a modification of Freundlich's adsorption isotherm. In the present study, variations in soil-water ratio were found to have an important influence upon the results secured with the quinhydrone electrode.

In this investigation 12 soils were studied with 5 different soil-water ratios, namely 2:1, 1:1, 2:3, 1:2, and 2:5. The soils vary from a fine sand to a heavy clay, and from a very acid soil to one distinctly alkaline. Table 6 shows the effect of varying the soil-water ratio on these soils.

It is apparent from the foregoing data that the hydrogen-ion concentration decreases as the soil-water ratio decreases. The same phenomenon has

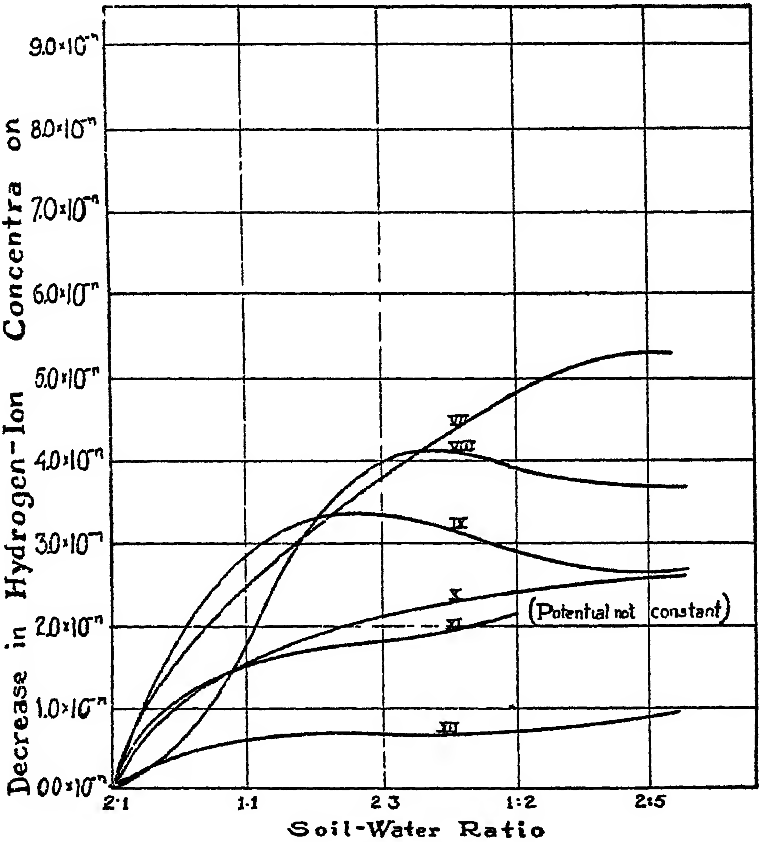

FIG. 2

VII = Soil 501. n = 6.
VIII = Soil 523. n = 9.
IX = Soil 528. n = 7.
X = Soil 101. n = 7.
XI = Soil 130. n = 6.
XII = Soil 30. n = 5.

been observed with the ordinary hydrogen electrode. In the results presented there is an almost consistent variation in pH of 0.3 between a ratio of 2:1 to 2:5. This shows the necessity of choosing some standard ratio to be used in this method. A comparison of these results with those in table 5

TABLE 7

Conversion of voltage to pH with the quinhydrone electrode and saturated calomel cell

E_q	pH	E_q	pH
−0.0485	8.50	0.1052	5.90
−0.0455	8.45	0.1082	5.85
−0.0425	8.40	0 1111	5.80
−0.0396	8.35	0.1141	5.75
−0.0366	8.30	0.1170	5.70
−0.0337	8.25	0.1200	5.65
−0.0307	8.20	0.1229	5.60
−0.0278	8.15	0.1259	5.55
−0.0248	8.10	0.1288	5.50
−0.0218	8.05	0.1318	5.45
−0.0189	8.00	0.1347	5.40
−0.0160	7.95	0.1377	5.35
−0.0130	7.90	0.1407	5.30
−0.0100	7.85	0.1436	5.25
−0.0071	7.80	0.1466	5.20
−0.0041	7.75	0.1495	5.15
−0.0011	7.70	0 1525	5.10
+0.0018	7.65	0.1555	5.05
0.0047	7.60	0.1584	5.00
0.0077	7.55	0.1614	4.95
0.0107	7.50	0.1643	4.90
0.0137	7.45	0.1673	4.85
0.0167	7.40	0.1702	4.80
0.0197	7.35	0.1732	4.75
0.0226	7.30	0.1761	4.70
0.0256	7.25	0.1791	4.65
0.0284	7.20	0.1820	4.60
0.0313	7.15	0.1850	4.55
0.0343	7.10	0.1879	4.50
0.0372	7.05	0.1909	4.45
0.0402	7.00	0.1938	4.40
0.0431	6.95	0.1968	4.35
0.0461	6.90	0.1997	4.30
0.0491	6.85	0.2027	4.25
0.0520	6.80	0.2056	4.20
0.0550	6 75	0.2086	4.15
0.0580	6.70	0.2115	4.10
0.0609	6.65	0.2145	4.05
0.0639	6.60	0.2175	4.00
0.0669	6.55	0.2204	3.95
0.0698	6.50	0.2234	3.90
0.0728	6.45	0.2263	3.85
0.0758	6.40	0.2293	3.80
0.0787	6.35	0.2322	3.75
0.0817	6.30	0.2352	3.70
0.0846	6.25	0.2382	3.65
0.0875	6.20	0.2411	3.60
0.0905	6.15	0.2441	3.55
0.0934	6.10	0.2471	3.50
0.0963	6.05	0.2500	3.45
0.0993	6.00	0.2530	3.40
0.1023	5.95	0.2559	3.35
		0.2589	3.30

for the ordinary hydrogen electrode indicates that the ratio of 1:1 with the quinhydrone method and of 1:5 with the ordinary hydrogen electrode give practically similar values. The ratio of 1:1 seems to be best adapted for this work. A graphic representation of the data shows this more clearly.

In figures 1 and 2, the soil-water ratio is plotted against the decrease in hydrogen-ion concentration below that observed at a soil-water ratio of 2:1. This method gives a good graphic representation of the data. In most of the curves a decided break comes in the proximity of the ratio of 1:1. This is added evidence of the desirability of selecting the 1:1 ratio for measurements by the quinhydrone method.

Conversion of volts into pH

In order to facilitate the reading of the hydrogen-ion concentration in terms of pH, table 7 was computed from equation G. It may be used to eliminate calculations after each reading. It is adapted for use only with a saturated calomel cell.

Table 7 shows that for every pH 0.05 there is a corresponding difference of 30 millivolts. If the observed voltage lies between any of the above values, the pH can be estimated to the second place. The temperature factor is 0.77 millivolts per degree deviation from 25°C.

CONCLUSIONS

A study of the quinhydrone method for determining the hydrogen-ion concentration soils leads to the following conclusions:

1. The saturated calomel cell is the most convenient to use since it is most constant and does not require a reversal of poles below pH 7.68.
2. For accurate results 0.05 gm. of quinhydrone per 15 cc. of solution is sufficient. The quinhydrone may be added in solution provided a fresh stock is prepared each day.
3. The potential is very constant with this electrode with the exception of soils above pH 8.0. It is reached quickly and easily.
4. The quinhydrone and ordinary hydrogen electrodes compare closely. Variations were obtained from 0 to 0.2 in pH, which is considered close enough for most soils work.
5. The most desirable soil-water ratio to use as a standard with the quinhydrone electrode is the ratio of 1:1. It gives results comparing closely with those obtained with the ordinary hydrogen electrode.

The quinhydrone method has a very distinct advantage over the ordinary hydrogen electrode inasmuch as the apparatus required is simpler, both in construction and operation, and requires a much shorter time to reach equilibrium. The method is applicable to field as well as laboratory purposes.

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COLLOIDAL BEHAVIOR OF SOILS AND SOIL FERTILITY: II. THE SOIL COMPLEX CAPABLE OF BASE EXCHANGE AND SOIL ACIDITY[1]

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INTRODUCTION

From the standpoint of soil genesis, dynamics, and methods of cultivation, those parts of the soil are of interest which show most activity in the soil processes and which create the differences among the various types. The native rock may be regarded as inert, for it adds no immediate fertility to the soil, although through the forces of weathering, the separation and formation of minute particles capable of taking part in the soil fertility processes occur. The larger particles play an important part mechanically. This mechanical support together with certain physical properties centered around the inert particles brings about a series of conditions which in their totality approximate what we know as soil fertility. The physical structure influences the aeration and thereby the oxidation processes which are chemical in nature.

If the practically inert quartz and other unweathered rock materials are excluded from the soil, the remaining portion will comprise the active components in which the life of the soil is centered. This portion of the soil has been named the zeolitic portion, but it is questionable whether the entire portion of the active soil is zeolitic. The vital importance of the organic portion in the life of the soil need not be emphasized here. None of the soil investigators would class these materials with the zeolites. This portion of the soil is very closely connected with what we understand under the term "colloidal fraction" of the soil. The process of soil development consists of the formation of this fraction and crystalloids, and the formation of various combinations and their distribution in the soil profile. The soil skeleton is passive and scarcely characterizes the types of soil. It is the so-called "colloidal fraction" which gives body and life to the soil, and which is in constant interaction with the soil solution, influencing its composition and suffering changes from the soil solution: it is this fraction which chiefly characterizes soils.

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[2] The authors share equal responsibility and credit for the work reported.

A further examination of this portion of the soil, shows that it is the one which is capable of base exchange, and it is this fraction, therefore, to which the soil investigator should direct his attention. A thorough appreciation of this soil complex capable of exchange will stimulate soil research in a definite direction. This trend of thought was clearly and extensively expressed by Sokolovski (13). The importance of such investigations has been pointed out also by Gedroiz (23) in his classical researches, by Hissink (7), by Wiegner (15), and by Kelley and Brown (11).

The extreme value of base exchange and of colloidal phenomena in investigations of soil problems has been demonstrated by the authors (8). In a footnote in one of the papers on "alkali soil studies" (8, paper III), the following statement was made:

> The theory of base exchange as outlined for the zeolites through the replacement of their cations by the hydrogen ions of the sulfuric acid presents a new aspect of soil acidity. We may picture it as follows: A soil becomes acid when its so-called zeolitic portion (the portion capable of exchange) is saturated with hydrogen and there are no more basic substances to be replaced and come out in solution. Only then will free acids (mineral or organic) or acid salts appear in the soil solution. Until then no real acidity, i.e., free acid, is possible. The zeolitic portion saturated with hydrogen may show acidity when treated with neutral salts. In this case the replacement process described in this paper takes place; in other words, the cation of the neutral salt replaces the hydrogen. These considerations have been suggested in the course of the alkali soil investigations and are now being looked into.

In a recent publication Glinka (5), the noted authority on soil classification, points out that the process governing the formation of soils is to be the basis of soil classification. The parent rock has only a secondary influence upon the process. The conditions which determine the making up of the soil complex capable of exchange should be especially emphasized, as the study of base exchange is the logical step toward a rational and scientific understanding of soil processes.

It is to be remembered that all the work on base exchange is based on the researches of Way, Van Bemmelen and others. A critical analysis of the earlier work will be given in a later paper of this series. A comprehensive review may be found in the papers of Gedroiz (2) and a more concise review in the publication of the California Station (11).

PROBLEM OF SOIL ACIDITY

Investigations on several factors relating to base exchange and soil colloids have been instituted in the laboratories of the New Jersey Agricultural Experiment Station. The following is a report of studies made on a phase connected with the phenomena of base exchange; namely, soil acidity.

The question of acidity in soils resolves itself into that of the state of "saturation" or "unsaturation"—terms introduced by Gedroiz (3)—of the soil complex capable of base exchange. By "unsaturation" we understand a condition whereby the bases of the soil complex capable of exchange have

been replaced by hydrogen. "Saturation" is the reverse of unsaturation. A soil solution with a concentration of hydrogen ions in equilibrium with the bases capable of exchange will react acid upon extraction with water, on account of the free hydrogen ions present in it. If the concentration of the hydrogen ions in the soil solution in the state of equilibrium mentioned is not reinforced, the hydrogen ions may finally be adsorbed in the soil complex and replace bases such as sodium, potassium, calcium, and magnesium. A water extract of such a soil will not indicate any acidity, but in reality the soil is acid, since the soil complex is becoming unsaturated. Such acidity may be termed "potential" acidity. From these considerations we may readily see how all grades of acidity, or all stages of unsaturation may exist even though a water extract will not show it. To obtain an accurate measure of the acid present in soil, a quantitative estimation of the state of saturation or unsaturation, must be made. To get an insight into this question, a quantitative study of the hydrogen ions present in various soils has been undertaken.

While this work was in progress, a paper by Gedroiz (4) appeared giving his method, which varies but little from the one used at the New Jersey Station, based on Gedroiz's previous work. Gedroiz realizing that his quantitative measurements are open to criticism, because of the use of litmus and methyl orange as indicators, suggests the possibility of using electrometric titration.

Potentiometric measurements of such solutions with the hydrogen electrode are erroneous because of the CO_2 factor. The bubbling of hydrogen through the solution to be tested forces out the CO_2 and, since the solution is not buffered, no accurate reading can be obtained. It was found that the colorimetric method gave accurate readings when properly manipulated.

EXPERIMENTAL

Ten-gram samples of the soil were shaken with 250 cc. of normal $BaCl_2$ solution, left in contact for 3 days, and filtered. The filtrate was then titrated with 0.02*N* KOH to pH 6.8. The soil on the filter paper was washed with $BaCl_2$ solution, fresh portions of the solution being added after all the previous solution had drained off. This washing was continued until a sample showed a reaction similar to that of the pure $BaCl_2$ solution. On the average it took from 3 to 5 liters of the normal $BaCl_2$ solution. The solution was titrated with 0.02 *N*KOH to a pH 6.8, brom cresol purple and phenol red being used as indicators. At the same time water extracts of these soils were made in the usual manner and the pH values determined. The pH of the $BaCl_2$ solution upon extraction was also determined.

The data in table 1 show that the water extracts of soils 6 and 7 with the pH of 6.4 and 6.2, respectively, give with the barium chloride solution a pH of 5.9 and 5.2, respectively. The water extract does not indicate any acidity, whereas the $BaCl_2$ extract shows appreciable acidity. The other samples show the same tendency toward increasing the H-ion concentration with the

$BaCl_2$ solution extract. The explanation is simple. The Ba cations have a very high coefficient of adsorption and replacement and enter the portion of the soil capable of base exchange forcing out the hydrogen ions present there. The wide variations between the pH readings of the water extract and the $BaCl_2$ extract clearly indicate that the pH determination of water extract is valueless from the standpoint of determining acidity in soils. It gives only a measure of the free hydrogen ions present in the soil solution. On the other hand the pH readings of the $BaCl_2$ extract give an indication of the state of saturation of the soil. The titer indicates the total acid present in the soil, and the degree of saturation.

Much has been written on the subject of soil acidity and more is forthcoming; as a great number of excellent reviews on the subject are easily accessible there is no need of repetition. A recent publication by Hager (6), however, deserves attention. His work represents a reaction against the pH fad, which has flooded the literature on soil science. Hager bases all his arguments and investigations on the researches of Kappen (10), who maintains that there is no active acidity in mineral soils, at least in the great majority of the so-called acid soils. Under "active acidity"—a term introduced by Veitch (14)—Kappen understands titrable acidity of a water extract, which indicates the presence of free acid or acid salts.

TABLE 1

H-ion concentration and titer of soil of Chenango series, Sussex Area

LABORATORY NUMBER	REACTION OF WATER EXTRACT	REACTION OF $BaCl_2$ EXTRACT	TOTAL TITRATABLE ACIDITY IN TERMS OF 0.02 *N* KOH
	pH	*pH*	*cc.*
1	5.4	4.6	10.05
2	5.4	4.6	15.00
3	5.4	4.6	11.55
4	5.2	4.8	8.60
5	5.2	4.8	8.85
6	6.2	5.9	1.90
7	6.0	5.2	3.85
8	6.0	5.8	2.10
9	5.6	5.2	3.70
10	5.8	5.4	4.05
11	5.0	5.0	5.75
12	5.8	5.8	1.30

Among the inorganic acids, sulfuric probably is the most generally found, since the sulfur compounds are biologically and chemically oxidized. The next acid of importance is nitric, which is an oxidation product of the nitrogen compounds. The other forms of free acid are the organic acids. In the process of decomposition of organic matter a number of organic acids of the methane, ethane, and other series appear. In the complicated system of the soil microbiological elements, there are times when organic acids are present

in the soil. They are, however, of transient nature, utilized by the various groups of microörganisms. Even the aforementioned inorganic acids are transient in nature, being affected by the bases released from the slowly decomposing silicates and compounds capable of base exchange. There is, however, a difference between the character of reactions in soil organic and inorganic acids. The organic acids in the process of decomposition leave as end-products CO_2 and H_2O, which, in one way or another are taken care of in the soil. The inorganic acids, releasing their hydrogen chemically, are temporarily tied up in the soil complex capable of base exchange, but are ready to appear at any time, when other cations are introduced. The question of active acidity, or free acid, resolves itself into the following:

In making a study of the soil acids, on account of the dynamic nature of the organic and even inorganic acids, erratic results are to be expected, especially if a water extract is used either for pH or for titration determinations. For the determination of free acid, water must be used, since any other solvent introduces complications. From what has been said and from a knowledge of base exchange, one may readily appreciate the condition, when such free acids are possible. First come the less important (from the standpoint of distribution) soils of organic nature, like peat and muck. In these, free organic acids are to be expected. When we come to mineral soils the picture is somewhat obscure. There is possibly a condition whereby the hydrogen ions of the free acids are in equilibrium with the bases capable of exchange, e.g. the hydrogen ions are in preponderance in the soil solution and the complex capable of exchange is unsaturated. At this time the H ions are circling around, from true solution into the solid phase of the complex and back again into solution, replacing themselves and thereby only slightly affecting the other cations. It is for this reason that an acid soil after losing a certain amount of bases shows only slight amounts of bases in the drainage. The free acids from inorganic source may be represented diagrammatically.

$$\underset{\text{solution}}{\text{H}} \rightleftarrows \underset{\text{solid phase}}{\text{H-complex capable of base exchange}}$$

The distribution of soils of an acid character as represented above is not so rare as was thought by Kappen (10), a view championed by Hager (6). *Undoubtedly soils that show a Sörensen value of pH 5.6 to 5.4 contain such free acids.* The free acid produced at this point may react with the silicates and bring aluminum and iron into solution. It is of interest to note that *precipitated $Al(OH)_3$ (the gel) will under certain conditions (anion effects) not go into the sol stage at pH 5.4 or even lower; the reaction is slow and in the presence of other electrolytes the conversion into gel may occur even at a low pH, e.g., the free acid may exist without aluminum in solution.* Experiments conducted in our laboratories corroborated the theory outlined.

A more detailed account of the work on Al and Fe in relation to pH and anions will be presented in a forthcoming paper.[3]

But leaving aside the active or free acid and approaching the subject of potential acidity, the replaceable H ions must be determined. For this purpose samples of soil from soil fertility plots 7A, 10A, 11A, and 12A of the New Jersey Experiment Station were used. Plot 7 receives no fertilizers; plots 10, 11 and 12 receive annual applications of 49.6 pounds of N per acre in the

[3] Since this paper has been written an interesting paper by Magistad (Soil Sci., v. 20, p. 181–227) on the Al problem has appeared. See also Niklas and Hock, 1925, Ztschr. Pflanzenernähr. u. Düngung., v. 5, p. 370–392.

forms of $Ca(NO_3)_2$ of $(NH_4)_2SO_4$, and $CaCN_2$, respectively. All plots except 7, receive an annual application of 102.4 pounds of P_2O_5 per acre in the form of acid phosphate and 160 pounds of K_2O in the form of KCl.[4]

Ten-gram samples were weighed out in Erlenmeyer flasks; 250 cc. of normal $BaCl_2$ was poured over them and allowed to stand for various periods of time, with stirring at intervals; the solution was filtered, titrated with 0.02*N* KOH, and the amount of acid calculated for each period. After 10 days of contact solution and soil were transferred on a filter and washed with $BaCl_2$ solution, as described, until the filtrate gave the same reaction in terms of pH as the $BaCl_2$ solution. The filtrate was titrated and the total amount of acid calculated. Wherever fairly large quantities of aluminum were apparent, allowances were made.

TABLE 2

Hydrogen-ion concentration, titer, and speed of replacement of H-ions in soils variously treated

LABORATORY NUMBER	KIND OF SOIL, PLOT NUMBER, AND YEAR OF SAMPLING	REACTION OF WATER EXTRACT	REACTION OF $BaCl_2$ EXTRACT	TITRATION OF 250 CC. $BaCl_2$ EXTRACT AFTER ONE HOUR*	TITRATION OF 250 CC. $BaCl_2$ EXTRACT AFTER 10 DAYS*	TOTAL TITRATABLE ACIDITY*	ACID EXTRACTED AFTER 1 HOUR CONTACT WITH $BaCl_2$	ACID EXTRACTED AFTER 10 DAYS CONTACT WITH $BaCl_2$
		pH	*pH*	*cc.*	*cc.*	*cc.*	*per cent*	*per cent*
	1914							
1	7A	5.6	4.8	2.20	4.15	9.60	23.0	43.2
2	10A	5.4	5.0	2.05	2.70	8.15	25.1	33.1
3	11A	5.4	4.4	4.40	6.70	14.40	30.5	46.5
4	12A	5.6	5.2	1.45	2.60	7.50	20.0	34.6
	1918							
5	7A	5.4	4.8	3.10	4.75	11.15	27.7	42.6
6	10A	5.6	5.0	1.70	2.95	8.15	20.8	36.2
7	11A	5.0	4.4	6.45	9.20	17.80	36.2	51.7
8	12A	5.6	5.1	1.05	2.20	6.80	16.0	32.3
	1922							
9	7A	5.2	4.6	4.10	6.50	12.15	33.7	53.5
10	10A	5.4	5.0	2.45	3.50	9.35	26.2	37.3
11	11A	4.8	4.4	7.75	12.10	22.30	34.7	54.2
12	12A	5.6	5.0	1.30	2.80	7.05	18.4	39.6

* In terms of 0.02 *N* KOH.

Table 2 gives the data of the experiment described. Again the pH figures of the water extract and those of the $BaCl_2$ extract do not correspond. Invariably the $BaCl_2$ extract shows more acidity than the water extract. This corroborates the statement made in connection with the Chenango soils (see table 1) that a determination of the H-ion concentration on a water extract does not give the true state of saturation and of unsaturation of the soils.

[4] For a detailed description of these plots the reader is referred to the annual reports of the New Jersey Agricultural Experiment Station, Department of Soil Chemistry and Bacteriology. The samples used were those taken from the plots in 1914, 1918, and 1922.

The data with $BaCl_2$ extract show that the soils, even the check plot, were acid and unsaturated in 1914. These figures give us only a qualitative picture, as may easily be deduced from a comparison of the pH determinations of the plots for the different years. They are practically the same, and yet the titration figures show how these soils gradually but surely become unsaturated.

It should be remembered that the soils contain in their complex capable of exchange a large amount of hydrogen; that when the stage of hydrogen aluminum silicates is reached and other bases, like Na, K, and Mg, are replaced, the soil becomes extremely acid; and that the water extract of such a soil is turbid[5] containing free aluminum. Preliminary experiments conducted to bring about a completely unsaturated condition (by washing with 0.05*N* HCl until practically no test for Ca or Mg in the filtrate could be obtained) showed that these hydrogen aluminum silicates are colloidal in nature, forming a colloidal sol when treated with water. Such a condition is being approached by plot 11A with a pH (water extract) of 4.6 to 4.8; the extract is turbid, for it contains an appreciable amount of silica and aluminum also some unsaturated organic complexes capable of base exchange. Long before all the bases are replaced free acid appears and the more acid the soil becomes the slower the remainder of the bases is replaced, for reasons pointed out; namely, the hydrogen ions are replacing themselves attacking the other bases but slightly. In the long run, however, all the bases are being replaced by hydrogen.

The titration data afford a clear picture of the amount of acid present in the soil complex capable of exchange, e.g., in the silicates known as "zeolites" and in the acid humates. It has been shown by Gedroiz (4) and Sokolovski (13) that humus contains various cations capable of exchange in equivalent quantities. Unsaturated humus may contain no basic cations at all. The titration data, therefore, give us the sum total of free or active acidity and of potential acidity of soils.

The figures in table 2 on the percentage of acid extracted after the first hour and after 10 days bring out some interesting features. First they show that after the first hour, as high as 36 per cent of the replaceable hydrogen was extracted from some soils. This indicates that the replaceable hydrogen is in a condition to be released from the solid phase (the complex capable of exchange) at certain equilibrium disturbances, notwithstanding the fact that in general the hydrogen ions stick very tenaciously in the solid phase.

Another feature to be noticed is the speed with which soils with various degrees of replaceable hydrogen give them up. The more acid soils suffered a loss of over 50 per cent of their replaceable hydrogen after 10 days of contact with the $BaCl_2$ solution; the less acid soils gave up only 32 to 37 per cent. The explanation must be sought in the energy of adsorption and replacement,

[5] The turbidity of such acid solutions is partly due to the unsaturated condition of the fraction of humus capable of base exchange. This subject will be taken up at a later date.

or as we called it "coefficient" of adsorption and replacement of the various cations. A soil less unsaturated (10A or 12A) contains in the solid phase in equilibrium with the soil solution, beside the hydrogen ions, some Ca and other cations. Introducing the Ba ion with a coefficient of replacement higher than the Ca, forces the latter out more energetically than the hydrogen ions, which possess a coefficient of adsorption higher even than Ba. However, on account of the great excess of the Ba ions (normal solution) the reaction in virtue of the mass action brings out some hydrogen ions. On the other hand in soil 11A with the hydrogen ion predominating in the solid phase, the Ba ion must struggle chiefly with hydrogen ions. Thus a greater speed of replacement results

In the form of chemical equations the various reactions may be represented as follows:

$$1)\quad \underset{\text{solid phase}}{4\,H^{+}\text{-colloids}} + 2\,Ba^{++} \rightleftarrows \underset{\text{solid phase}}{2\,Ba^{++}\text{-colloid}} + 4\,H^{+}$$

$$2)\quad \underset{\text{solid phase}}{\left.\begin{matrix} 2\,H^{+}\text{-colloids} \\ Ca^{++}\text{-colloids} \end{matrix}\right\}} + 2\,Ba^{++} \rightleftarrows \underset{\text{solid phase}}{2\,Ba^{++}\text{-colloids}} + 2H^{+} + Ca^{++}$$

Thus in equation 1, representing the more acid soils, more H-ions are to be expected with the same number of Ba ions entering the complex.

These considerations open up the problem of the effects of fertilization on replacement of cations; this subject will be touched upon presently.

The process of continuous washing of the soil with the neutral $BaCl_2$ solution to obtain all the replaceable hydrogen from the complex is slow. In order to speed up the reaction the use of the normal solution has been found to be the most practical, although higher concentrations of $BaCl_2$ did replace the hydrogen somewhat faster. The cost involved did not warrant the use of concentrations higher than normal, and in many instances 0.5 *N* has given just as good result. Table 3 gives a few figures[6] on the effect of concentration of $BaCl_2$ on replacement of hydrogen ions. It is apparent that the higher the concentration the faster is the replacement, but the increase in replacement is in no way proportional to the concentration.

There is, however, another phase of the subject which the data in table 3 suggest; namely, the effect of fertilization on the process of replacement.

One may easily surmise that even after a heavy application of fertilizers the soil solution will not at any moment contain a concentration of salts equivalent to normal. The tendency is toward a dilute solution and for this reason one should expect neither any rapid accumulation, nor any release of hydrogen ions. This subject is of extreme importance and as more data will accumulate in connection with the study of the capacity of the soils for base exchange, more light will be shed on this interesting phase of the work.

[6] More data on this phase of the subject are on hand, but being of the same nature as in table 3 they are omitted here.

TABLE 3

Effect of concentration of replaceable cations on replacement of hydrogen ions

KIND OF SOIL AND CONCENTRATION OF $BaCl_2$ SOLUTION	0.02 *N* KOH USED IN TITRATION OF $BaCl_2$ EXTRACTS* AFTER:						
	1 day	2 days	4 days	5 days	6 days	7 days	8 days
	cc.	*cc.*	*cc.*	*cc.*	*cc.*	*cc.*	*cc.*
7A							
0.001 *N*	0.30	0.37	0.20	0.25	0.30	0.40	0.25
0.01 *N*	0.65	0.37	0.50	0.40	0.40	0.40	0.50
0.1 *N*	1.50	1.00	1.40	1.30	1.15	1.20	1.25
0.5 *N*	1.65	1.90	1.95	2.05	2.10	2 05	2.20
10A							
0.001 *N*	0.40	0.20	0.25	0.18	0.30	0.25	0.30
0.01 *N*	0.45	0.30	0.35	0.35	0.35	0.25	0.35
0.1 *N*	0.80	....	0.60	0.65	0.70	0.70	0.70
0.5 *N*	1.05	....	1.10	1.10	1.15	1.30	1.20
11A							
0.001 *N*	0.65	0.35	0.45	0.35	0.45	0.40	0.40
0.01 *N*	1.75	1.20	1.50	1.45	1.40	1.30	1.40
0.1 *N*	2.90	3.10	3.35	3.10	3.20	2.90	3.05
0.5 *N*	3.85	3.90	4.30	4.20	4.25	4.20	4.35
12A							
0.001 *N*	0.30	0.15	0.25	0.15	0.25	0.20	0.25
0.01 *N*	0.45	0.10	0.35	0.30	0.30	0.20	0.20
0.1 *N*	0.50	0.20	0.30	0.30	0.45	....	0.30
0.5 *N*	0.40	0.75	1.00	0.95	0.90	0.60	0.75

* 5 gm. of soil with 125 cc. of $BaCl_2$ solution was used.

TABLE 4

Effect of temperature on speed of replacement of cations in soils

[illegible]	$BaCl_2$ EXTRACTS*	
	1 hour at 65°C.	Room temperature
	cc. 0.02 N KOH	*cc. 0.02 N* KOH
181	3.50	3.60
182	8.15	8.50
187	3.35	3.40
188	2.30	2.85
191	2.25	2.40
192	0.45	0.60
189	0.80	0.95
190	0.45	0.50
197	0.80	1.10
198	0.90	0.95
193	1.95	1.95
194	0.45	0.60

* 10 gm. of soil with 250 cc. of normal $BaCl_2$ were used.

It is known in general that heat speeds up chemical interaction. On an average, other things being equal, every rise of 10° doubles the amount of material changed each second.

In an attempt to speed up the reaction of replacement, by heating, several series of experiments were conducted. The soils were mixed with normal

TABLE 5

Titratable acidity with normal $BaCl_2$ and KCl solution extracts at various contact intervals

SOIL NUMBER	$BaCl_2$ EXTRACT						KCl EXTRACT				
	cc. of 0.02 *N* KOH after:						cc. of 0.02 *N* KOH after:				
	1 hour	1 day	3 days	5 days	7 days	10 days	1 day	3 days	5 days	7 days	10 days
	Plot soils										
1914											
7A	2.20	2.90		3.50	4.00	4.15		2.55		2.65	
10A	2.05	2.60		2.90	2.90	2.70		1.80	1.90	1.85	
11A	4.40	5.25		6.05	6.70	6.70					
12A	1.45	2.00	2.20		2.50	2.60		1.60	1.50	1.60	
1918											
7A	3.10	4.10	4.20		4.60	4.75		3.20	3.50	3.20	3.55
10A	1.70	2.20	2.00		2.90	2.95		1.85	1.90	2.00	2.30
11A	6.45	7.90	8.50		9.60	9.20		8.25	8.10	8.60	8.60
12A	1.05	1.70	1.70		2.20	2.20		1.20	1.15	1.80	1.70
1922											
7A	4.10	5.35	5.60		6.30	6.50		4.80	5.00	5.10	5.25
10A	2.45	2.75	3.00		3.35	3.50		2.00	1.95	2.55	2.40
11A	7.75	9.65	10.55		11.60	12.10		10.50	10.80	10.80	11.20
12A	1.30	2.15	2.15		2.25	2.80		1.55	1.60	1.80	1.80
	Chenango series										
SOIL SURVEY NUMBER											
181	3.60	4.60	4.80	4.80	5.25	5.05	2.60	2.50	2.80	2.90	3.05
182	8.50	9.40	9.40	9.50	9.95	9.80	9.60	10.20	10.80	10.65	10.75
187	3.40	4.65	4.95	5.10	5.35	5.40	4.90	5.30	5.35	5.75	5.65
188	2.85	3.10	3.35	3.25	3.25	3.30	4.90	5.00	5.25	5.55	5.45
191	2.40	3.25	3.50	3.35	3.40	3.50	2.00	2.00	2.10	2.30	2.30
192	0.60	0.75	0.65	0.70	0.75	0.75	0.75	0.95	1.10	1.15	1.10
189	0.95	1.25	1.45	1.40	1.35	1.25	0.50	0.45	0.65	1.15?	0.60
190	0.50	0.70	0.65	0.65	0.75	0.70	0.70	0.75	0.75	0.75	0.70
197	1.10	1.35	1.45	1.45	1.65	1.70	0.80	0.85	0.90	0.95	1.00
198	0.95	1.00	1.10	1.10	1.30	1.20	1.25	1.20	1.00	1.25	1.25
193	1.95	2.50	2.75	2.90	3.00	3.00	3.20	3.50	3.60	3.80	3.75
194	0.60	0.95	1.00	0.80	0.95	0.95	1.50	1.55	1.60	1.70	1.70

$BaCl_2$ or KCl, heated at various temperatures, and filtered. The filtrate was titrated in the usual manner with 0.02 *N* KOH. To save space, table 4 gives data on one temperature and on one series of soils only. It will be seen that the rise in temperature decreased the speed of reaction, or increased it in

a negative sense. What apparently happened was: Heat causes coagulation in colloid reactions; which in turn decreases the specific surface and thus decreases reactivity; consequently, the placement process slowed down.

Gedroiz (3, p. 21) states that the reaction of mutual exchange of cations is instantaneous. In his experiments the amount of cations replaced (as calculated from the Ca) does not differ from the time of contact. The figures on the titration in tables 2 and 5 and curves 1, 2, and 3 show that there is a gradual increase in replacement with the time of contact. The reaction comes to an equilibrium after 7 to 10 days of contact. More prolonged contact did not increase the amount of hydrogen replaced. The curves also show that the greatest replacement takes place within the first 24 hours.

When table 5 is examined more closely, several interesting features appear. First, we note that in the plot soils the speed of replacement with the $BaCl_2$ solution is invariably greater than with the KCl solution. On the other hand, in the Chenango series the greater speed of replacement with the $BaCl_2$ solution is true only in several of the samples; a few samples show practically the same speed of replacement for both the $BaCl_2$ and KCl solutions. There are a few samples with a distinct tendency toward a greater speed of replacement with KCl solution. From knowledge of the adsorption coefficients and of the replacement of the various cations, one should expect the Ba ion, a bivalent ion, to replace other cations faster than K ion would. This theoretical background finds support in the analyses of the data on the plot soils.[7] But why the inconsistency with the Chenango soils? Thus far no satisfactory explanation can be offered. Preliminary experiments in an effort to solve the problem pointed toward a survey of the capacity of the various soils for replacement and an inventory of the cations present in the complex capable of exchange.

Table 5 also shows that not all of the soils possess the same speed of replacement; this feature has been pointed out in connection with the discussion of table 2. There is, however, another angle of this phenomenon; namely, the relationships arising from reactions governed by the nature of the colloid substance involved.

As previously mentioned, it is the colloid fraction of the soil that is responsible for the reactions in base exchange. The mode of the reactions naturally depends upon some of the fundamental ideas of colloid chemistry, and a few preliminary remarks may help to throw more light on the subject of speed of reactions.

One of the chief characteristics of colloid reactions is their surface nature. With an increase in the degree of dispersion of particles or, as Ostwald (12) prefers to call it, "the specific surface," the reactivity of the dispersed phase

[7] It may be of interest to note here that data with NH_4Cl solution seem to show that the coefficient of adsorption and replacement of NH_4 ion follows the K ion; this is in accord with the octet theory of valence as presented by Langmuir; see Jour. Amer. Chem. Soc., v. 42, p. 274; v. 38, p. 221; v. 40, p. 1361.

increases. If, for the sake of illustration, the cubical structure of particles is assumed, table 6 (taken from Ostwald) gives an idea of the increase in surface.

The nature of the plot soils is such that in 11A the colloids involved are more dispersed than in the other soils because of unsaturation. A water extract of this soil is turbid; showing that the H ions peptized the colloids, increasing its specific surface and hence its reactivity.

TABLE 6

Increase in the surface of a cube with progressive decimal subdivision

LENGTH OF ONE EDGE	NUMBER OF CUBES	TOTAL SURFACE	SPECIFIC SURFACE
1 cm.	1	6 sq. cm.	6
1 mm.	10^3	60 sq. cm.	6×10^1
0.1 mm.	10^6	600 sq. cm.	6×10^2
0.01 mm.	10^9	6000 sq. cm.	6×10^3
1.0 μ	10^{12}	6 sq. m.	6×10^4
0.1 μ	10^{15}	60 sq. m.	6×10^5
0.01 μ	10^{18}	600 sq. m.	6×10^6
1.0 $\mu\mu$	10^{21}	6000 sq. m.	6×10^7
0.1 $\mu\mu$	10^{24}	6 hectares	6×10^8
0.01 $\mu\mu$	10^{27}	60 hectares	6×10^9
0.001 $\mu\mu$	10^{30}	6 sq. km.	6×10^{10}

TABLE 7

Suction force of limed and unlimed soil

SOIL NUMBER*	SUCTION FORCE: RISE OF MERCURY COLUMN
	cm.
7A	28.1
7B	25.0
11A	24.6
11B	21.5
10A	28.0
10B	25.6
12A	21.9
12B	18.1

* For fertilizer treatments see pages 185–186 of this article. The A and B plots are treated identically, but receive applications of from 2000 to 4000 pounds of lime every 5 years.

The effect of the degree of dispersion is brought out more clearly in the time rate curves. (Figs. 1, 2, and 3). They resemble true adsorption curves as outlined by Freundlich (1), being in reality replacement curves; the adsorbed hydrogen ions arrange themselves on the surface and, if other cations are present, have to share the space with them. For this reason the more acid soils are dispersed more highly and react with a greater speed. The parallelism of the curves shows that the various soils possess the same type of colloid substance, varying only in degree of dispersion. It is easy to predict from the time rate curves the so-called "colloidality" of the soil.

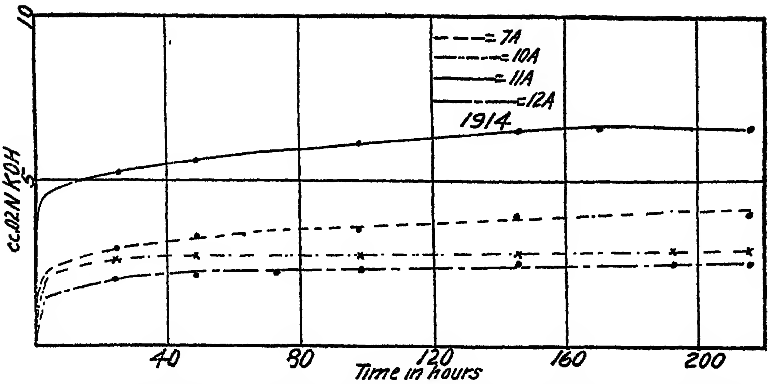

FIG. 1. TIME RATE CURVES OF SOILS 7A, 10A, 11A, AND 12A FOR 1914

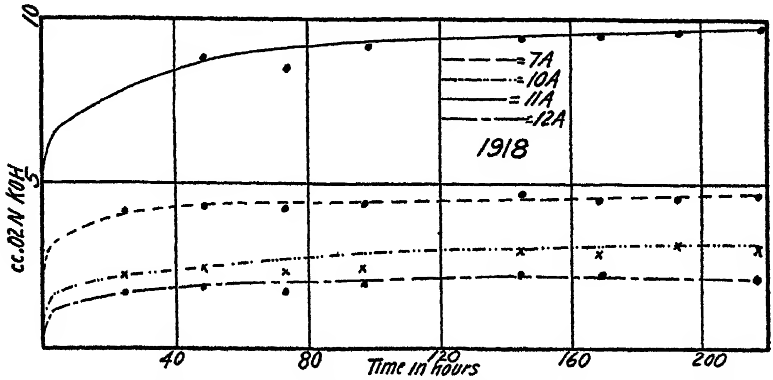

FIG. 2. TIME RATE CURVES OF SOILS 7A, 10A, 11A, AND 12A FOR 1918

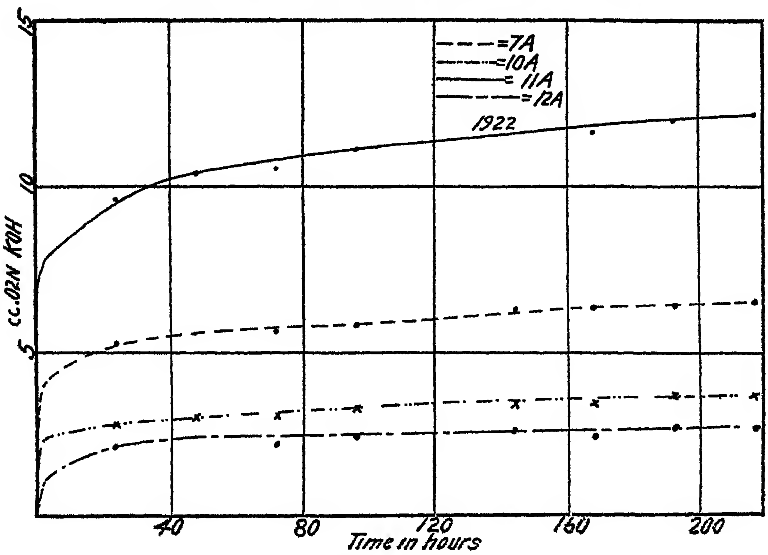

FIG. 3. TIME RATE CURVES OF SOILS 7A, 10A, 11A, AND 12A FOR 1922

That the colloidality of the soil is increased with the increase of the replaceable H ions has been pointed out in the first paper of this series (9). Table 7 gives the data on the suction force of limed and of unlimed soils. This suction force is an expression of the colloidality of the soil.

The lime as a coagulating agent, therefore, depresses the degree of dispersion of the soil colloids whereas the hydrogen peptizes the colloids, increasing their reacting surface.

The relation of the degree of dispersion brought about by increased acidity to lime requirement of soil will be the subject of the next paper.

SUMMARY

The subject of the rôle of the soil complex capable of base exchange or of the colloid fraction is analyzed and discussed.

The problem of soil acidity is reduced to the question of state of saturation and unsaturation of the soil complex capable of base exchange.

Experiments were conducted to determine quantitatively the amount of hydrogen ions present in the soil complex.

It is shown that the measurements of the H ion content in a water extract of soils add very little to our knowledge of the state of saturation or unsaturation. They give only an idea of the free acid present.

The cycle of replacement of H ions in the presence of other cations is discussed; the effect of this cycle on the Al-ions is presented.

The potential acidity, or the replaceable H ions, of some of the soil fertility plots of the New Jersey Experiment Station was determined quantitatively.

The speed of cation replacement is linked with the colloidal nature of the soils investigated.

Data presented show the effect of concentration of replaceable cations on the speed of replacement in the colloid fraction of the soil.

Temperature effects bring about a coagulation of the colloids and thus a slowing down of the replacement reactions.

Time rate data show that replacement is speeded up by longer contact within certain limits.

The time rate curves show typical adsorption curves. They point toward the colloidality of the soils, corroborating the determinations made on the colloidality of the soil by the suction force method.

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A STUDY OF SOME OF THE FACTORS AFFECTING THE SUPPLY OF MOISTURE TO CROPS IN SANDY SOILS[1]

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The sandy soils of Wisconsin, as well as of other states, present a problem of no small dimensions to those who are actively engaged in utilizing them for the purpose of crop production. This fact may be emphasized more concretely by stating that approximately six million acres, ⅙ of the total area of the state, are recognized as sandy soils. Many areas of considerable size are very densely populated; some are undergoing development; and others are still in the virgin state. As the acreage of these soils under cultivation increases, the greater, from an economic point of view, becomes the problem of profitable crop production.

Among the factors upon which successful crop production depends is that of fertile soil. To qualify as such, the soil should first, possess a favorable moisture supply; second, contain sufficient air; third, possess the quality of good tilth, fourth, contain a good supply of available plant-food elements; and fifth, be free from harmful influences. The two most important of these as related to sandy soils are the first and fourth, the effectiveness of the latter being largely dependent upon the former.

The mean annual rainfall for Wisconsin, as cited by Whitson and Baker (30), is 31 inches, about half of which comes in May, June, July and August, and nearly 70 per cent from April to September inclusive. This amount with its favorable distribution normally supplies the needs of crops over the state as a whole.

The utilization of the rainfall by crops, however, is closely related to the water-holding capacity of the soil, which, in turn, is governed largely by its texture and structure. Sandy soils, as a group, are coarse-textured, open soils of relatively low water-holding capacity. The effect of this is all too frequently reflected in materially decreased yields of crops grown upon them.

[1] Part of a thesis submitted to the Faculty of the Graduate School, University of Wisconsin, in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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PURPOSE

The three most important classes of sandy soils from the standpoint of their distribution are medium sand, fine sand and sandy loam. It is the purpose, therefore, of this investigation to study some of the factors affecting the supply of moisture to crops in these three soil classes.

REVIEW OF LITERATURE

Reports on the results of parallel investigations are few. Many studies have, however, been made on closely related phases, some of which may well be considered.

The rate and amount of percolation of water has an important bearing upon the utilization of rainfall by crops. King (16) in his irrigation experiments on Plainfield sand shows that an application of 0.75 inch of water on sand containing an initial moisture content of 9.17 per cent reached a depth of 3 feet during 21 hours, and emphasizes the fact that when much more than one inch of water is applied at once, percolation is likely to occur. Suprunenko (28) notes a somewhat less rapid rate. Harris and Turpin (13) find that 0.1 inch of rainfall on a loam under dry-farming conditions cannot be detected in moisture determinations soon after, but within a short time a 0.5 inch fall increases the moisture content to a depth of 6 feet. Burr (8) finds that an inch of rain falling upon a very dry surface of fine sandy loam will seldom penetrate to a depth greater than six inches. King (14, 15), working with 10-foot columns of sands and of a sandy loam, shows that water in moist soils establishes itself in a gradient, the least at the top and the most at the bottom of the column, regardless of the previous distribution. Briggs (3) and Briggs and Lapham (4) find the most moisture nearest the source of supply and the least, farthest away.

Irrigation studies by Loughbridge (20) show the downward movement of water through a sandy loam to be very irregular in its rate and in the amount retained at various depths.

Columns of sandy loam, 7 feet long, with no evaporation, are shown by King (15) to retain 23.27 inches of water after draining 60 days.

The influence of soil type upon percolation is shown by Fraps (9) in three years work with 24-inch columns of four uncultivated heavy and sandy soils. The average annual rainfall during the period was 33.45 inches. He finds the average percolation for the three years from the clay and clay loam group to be twice as much (12.72 inches) as that from the sandy loam group (6.36 inches). The results are explained by the fact that the sandy group lost much greater quantities of water by evaporation than did the clay group.

It has been shown by Principi (25) and Fraps (9) that evaporation is most rapid from materials which have the largest pore spaces; the former (25) demonstrates that evaporation remains almost the same whether it arises from a free water surface or from thin films covering the particles of the wet material. Mohr (24) states that evaporation at the beginning is greater from wet soil surfaces than from a free water surface, but finally decreases until the reverse order is obtained. Harris and Robinson (12) and Wollny (31) on the other hand find a gradual increase in evaporation from graded sand particles as the size decreases.

The evaporation from the moist surfaces of Janesville loam and Norfolk sand for a season is shown by King (17) to be 25.26 and 27.27 inches, respectively. He (16) also finds a much greater evaporation of water from a free water surface than from that supplied by rainfall for the corresponding period. Meyer (23) states that about 50 per cent of the evaporation from land occurs within three days after precipitation.

Buckingham (7), studying the drying of soils under arid and humid conditions, finds a much greater rate of evaporation under the former during the first four days, but the total loss of moisture becomes and remains greater under the latter conditions.

That soils possess a great attractive and adhesive force for water has been established by Bouyoucos (2). The comparative magnitude of these forces in different soils is expressed by Schull (27), Briggs and Shantz (6), and Briggs and McLane (5).

Wollny (31) and Krakov (18) show that capillary rise in coarse-textured soils is less than in fine, but that the rate of rise is at first directly proportional to the coarseness of the particles. Later, however, the reverse is true.

The idea that capillarity plays a very important rôle in supplying moisture to crops is gradually being discredited. Tulaykov (29), Gardner (10), Burr (8), Buckingham (7), and Lee (19) show the capillary lift of sandy soils to be low. The results of the work of Lynde and Dupre (21) on soil separates are likewise in close agreement.

Rotmistrov (26) concludes that water percolating beyond a depth of 16 to 18 inches in a clayey soil returns to the surface only by means of the roots of plants, and all waters not so utilized go down into the deeper layers of the soil, moving at a yearly rate of about seven feet.

He says: "As regards the circulation in an upwards direction, there exists a wrong impression, which our literature has almost made a household word. It is maintained that water can rise to the surface from the *deep* layers by capillary action. I shall not name the authors who maintain this theory—they are too numerous; but I do not know of a single author who could prove this proposition. Of course, by 'deep' soil layer almost any measurement may be understood: 50 or 200 cm., 35 or 70 feet. . . . . Consequently by the word 'deep' must be understood those layers into which the roots of cultured plants do not strike."

EXPERIMENTAL CONDITIONS

A part of the experimental work was performed on soils transferred from the field into cylinders placed under somewhat different climatic conditions; the remainder, on field plots under nearly uniform climatic conditions.

Cylinders

Work with cylinders was conducted as three experiments:

Experiment I, begun in 1916, included a series of 27 cylinders at Madison; Experiment II, begun in 1920, a series of 6 cylinders at Madison; Experiment III, begun in 1922, a series of 18 cylinders at the Experimental Farm at Hancock, Wisconsin.

The heavy galvanized iron cylinders are 18 inches in diameter. Each one is provided with a ½-inch drainage pipe, ½-inch above the bottom. A small amount of gravel was placed over the openings of the drain pipes to prevent them from clogging with soil. All cylinders in the second experiment at Madison and the third experiment at Hancock (figs. 2 and 3) are 53 inches in height and are sunk 18 inches apart, with their tops flush with the surface of the ground, the former within a screened inclosure. In the first experiment (fig. 1) cylinders 1, 10, and 19 are 27 inches; 4, 13, and 22, are 78 inches; and the remainder, 53 inches in height. In setting these cylinders, 3 trenches—34.5 feet in length—were dug to depths corresponding to the heights of the cylinders. To insure adequate drainage, a tile drain was laid beneath the bottom of the trench in which the tallest cylinders were to be placed. Vitrified sewer tile, 22 inches in diameter, were then set in a vertical position flush with the surface of the ground so that the bells of the exposed joints were 18 inches apart in one direction and 12 inches in the other. That portion of the trenches not occupied by the tile was filled with the excavated soil. The cylinders, which were within a screened inclosure, were then set within the appropriate tile and later filled with soil.

Experiment IV included 3 series of plots, of 3 plots each, which were established on farms in the vicinity of Hancock, Wisconsin, during the early spring of 1921. (Fig. 4.) The medium sand (100 series) and the sandy loam (300 series) plots were laid out in a north and

south direction; the fine sand (200 series) plots lie in an east and west direction. The medium sand series is level throughout; the fine sand series slopes gently to the west; and plot 2 of the sandy loam series slopes gently to the north to plot 3, which has slightly less elevation

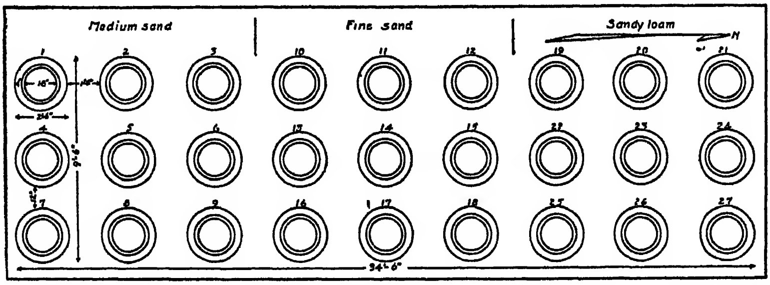

FIG. 1. ARRANGEMENT OF CYLINDERS IN EXPERIMENT I AT MADISON, CONTAINING MEDIUM SAND, FINE SAND, AND SANDY LOAM

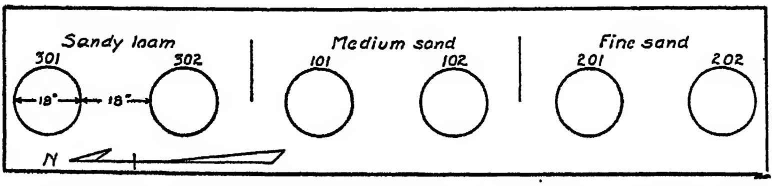

FIG. 2. ARRANGEMENT OF CYLINDERS IN EXPERIMENT II AT MADISON, CONTAINING MEDIUM SAND, FINE SAND, AND SANDY LOAM FROM EXPERIMENTAL PLOTS NEAR HANCOCK

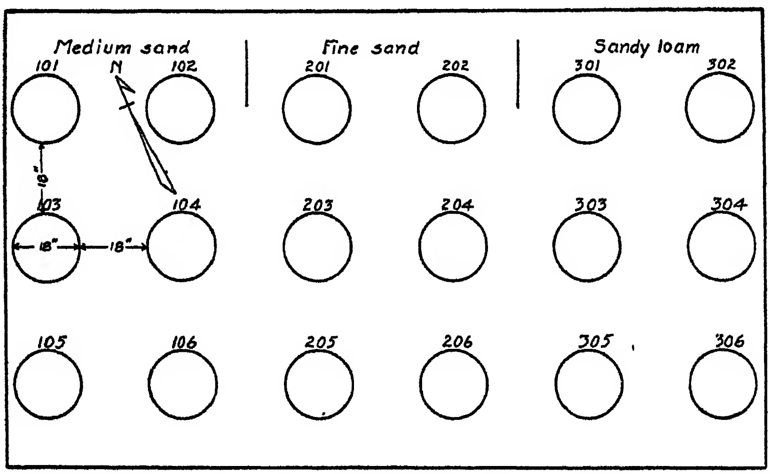

FIG. 3. ARRANGEMENT OF CYLINDERS IN EXPERIMENT III AT THE HANCOCK EXPERIMENTAL FARM, CONTAINING MEDIUM SAND, FINE SAND, AND SANDY LOAM FROM EXPERIMENTAL PLOTS NEAR HANCOCK

than plot 1. The individual plots were 2 rods square—enclosing an area of $\frac{1}{40}$ of an acre. They were separated by $\frac{1}{2}$-rod division strips and surrounded by a $\frac{1}{2}$-rod border strip. A general view of these series is shown in plate 1.

Soils

The soils employed in all experiments belong to the Coloma series and are recognized as Coloma sand, Coloma fine sand, and Coloma sandy loam in the United States Bureau of Soils classification.

The medium sand consists of loose sand of medium texture, very light brown, to a depth of 7 inches. At this point the color changes rather abruptly to a brownish-yellow for a few inches and then grades into a golden yellow to a depth of at least 40 inches. The texture is quite uniform.

The surface soil of the fine sand consists of a light yellow, loose sand of fine texture to an average depth of 8 inches, where it gradually grades into a darker yellow, slightly more compact, fine sand. At an average depth of 24 inches the color changes to a golden yellow, which persists to 40 inches.

The sandy loam consists of a brown, loamy, medium sand to a depth of eight or nine inches. At this depth it grades into a brownish-yellow, loamy sand and becomes somewhat coarser in texture to a depth of 24 inches. From 24 to 36 inches the subsoil consists of a yellowish-brown, sticky, sandy loam containing some stones and bowlders, beneath which the soil becomes somewhat more open

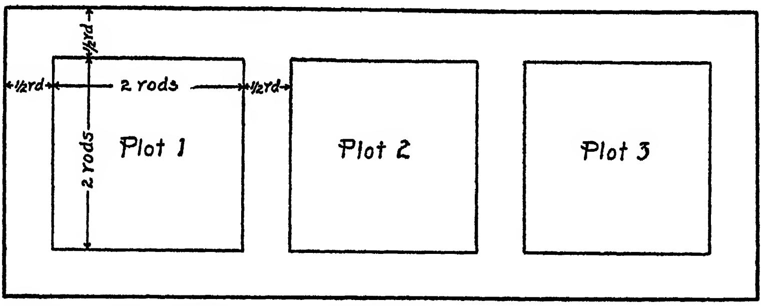

Fig. 4. Arrangement of Plots in Experiment IV in Each of the Three Series of Plots Near Hancock

The soils used in experiment I at Madison were collected[8] before the plot areas were established and consequently vary somewhat in mechanical composition from the soils used in experiments II and III which were collected from the plot areas of experiment IV. A mechanical analysis was made in duplicate from well composited samples of each soil, according to the method used by the Bureau of Soils of the United States Department of Agriculture. The average results are given in tables 1 and 2.

Inspection of the above data shows the medium sand and the fine sand to be within their prescribed limits. The sandy loam, however, contains less than the lower limit of 20 per cent of silt and clay.

The organic matter content in table 1 was determined by multiplying the organic carbon by the factor 1.724. These determinations were made in duplicate. The Truog test for soil acidity showed all soils to be from slightly to mediumly acid.

[8] Collected by Professor E. J. Graul.

TABLE 1

Mechanical composition, organic matter and moisture equivalent of medium sand, fine sand, and sandy loam used in experiment I in cylinders 1-27 at Madison

SOIL CLASS	DEPTH	FINE GRAVEL	COURSE SAND	MEDIUM SAND	FINE SAND	VERY FINE SAND	SILT	CLAY	TOTAL	ORGANIC MATTER	MOISTURE EQUIVALENT
		per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	
Sand..........	Surface	1.88	6.57	28.89	43.63	8.12	6.60	4.17	100.86	1.00	5.89
	Subsoil	2.15	6.54	31.46	44.64	5.87	5.97	3.61	100.24	0.40	4.14
Fine sand.....	Surface	0.28	1.20	15.08	67.30	9.03	3.46	3.81	100.16	0.56	4.24
	Subsoil	0.03	0.99	13.30	73.13	9.42	1.69	2.54	101.10	0.24	2.24
Sandy loam...	Surface	2.27	2.60	13.28	43.69	21.02	14.12	4.11	101.09	1.08	8.28
	Subsoil	5.18	4.53	17.88	38.96	18.78	10.78	3.74	99.95	0.29	8.64

TABLE 2

Mechanical composition of soils used in experiments II, III, and IV, from field plots near Hancock

DEPTH	FINE GRAVEL	COURSE SAND	MEDIUM SAND	FINE SAND	VERY FINE SAND	SILT	CLAY	TOTAL
inches	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
				Coloma sand				
0–6	0.29	16.28	40.07	29.14	4.32	5.80	3.88	99.78
6–12	0.40	20.58	42.74	24.76	3.71	4.85	3.60	100.64
12–18	0.45	17.86	42.60	28.69	3.07	4.29	3.54	100.50
18–24	0.40	20.15	44.28	27.05	2.32	3.08	2.89	100.17
24–30	0.47	19.04	41.88	30.06	3.13	2.48	2.59	99.65
30–36	0.37	19.67	42.18	30.26	3.01	2.33	2.25	100.07
36–40	0.37	15.77	40.13	34.04	4.96	2.66	2.24	100.07
				Coloma fine sand				
0–6	0.11	7.32	27.31	51.53	5.92	4.86	4.66	101.71
6–12	0.19	7.31	25.47	52.36	6.05	4.65	3.67	99.70
12–18	0.17	7.36	24.96	54.41	5.22	3.96	3.45	99.53
18–24	0.16	8.11	25.56	54.17	5.71	2.89	3.55	100.24
24–30	0.10	6.33	23.08	58.86	6.60	2.00	3.07	100.04
30–36	0.30	8.46	26.62	55.30	6.34	1.57	2.32	100.91
36–40	0.16	6.36	24.57	59.91	5.81	1.33	1.84	99.58
				Coloma sandy loam				
0–6	0.30	9.92	20.82	36.41	13.69	14.08	4.85	100.07
6–12	0.27	8.79	20.61	40.52	13.48	11.71	4.37	99.75
12–18	0.49	11.77	23.77	38.37	12.38	9.17	4.10	100.05
18–24	0.30	12.65	24.70	36.71	11.62	7.90	6.26	100.14
24–30	0.31	12.18	22.57	35.20	13.67	9.02	7.76	100.71
30–36	0.64	14.49	26.12	31.90	10.78	8.64	7.61	100.18
36–40	0.68	13.51	25.63	33.05	11.60	7.72	7.61	99.80

The moisture equivalents in table 1 were determined in duplicate according to the method developed by Briggs and McLane (5).

In collecting the soils for the cylinder experiments, the different strata were taken separately and placed in their natural order in the cylinders. During the process of filling, the soils were tamped to approximate field conditions of compaction.

Rotation of Crops

In the spring of 1917 a 3-year rotation of corn, oats, and medium red clover was started in connection with experiment I. A crop of clover was harvested that year, but during the following winter and each succeeding one, the clover seeding was killed and soybeans were substituted in its place. Each crop was grown each year.

In experiment II one rotation of corn, oats, and soybeans was completed, one crop being grown each year.

A rotation of corn, rye and soybeans was followed in experiment III, each crop being grown on each class of soil each year.

When the plots in experiment IV were established, a 3-year rotation of corn, oats, and clover was planned, but was changed in 1922 to corn, rye, and clover. Clover was seeded with oats in 1921 but as it did not survive the winter following, soybeans took its place in 1922.

Fertilizer Treatment

An attempt was made to supply sufficient plant-food materials to the soils so that the moisture supply, as determined by the texture of the soil, would be the limiting factor in crop production. The fertilizers were applied broadcast and were well worked into the surface in amounts sufficient to meet the requirements of each crop. Group limestone was applied at the required rates as indicated by the Truog test for soil acidity.

Moisture Determinations

Samples of each of the three classes of soils were collected in experiment IV at varying intervals for moisture determinations, of which over 1200 were made during the 3-year period. Determinations were made on each individual plot. Samples at 6-inch intervals were taken to a depth of 36 inches, and at a 4-inch interval, to 40 inches. The composites from which the determinations of each were made were secured from three different portions of the plot. The samples were taken by means of a King soil sampler.

The first four sets of determinations in 1921 were made on the entire composite for each depth in large tin boxes with tightly fitting covers. Between 400 and 500 gm. of soil were used, the weighing being made on a Troemner solution balance. Later, however, small portions—about 50 gm.—of the composites were placed in small aluminum weighing boxes with tight fitting covers and the weighings made on an analytical balance.

The samples were dried at 106° to 108°C. in ovens placed above a four-burner Perfection oil stove. A thermometer was inserted through the side of each oven from which the temperature of the ovens was observed. The flames were regulated to hold the ovens within a 2-degree variation of temperature.

Rainfall

During the growing season of 1917 a record was kept of the amount of rain received within the screened enclosure at Madison. It so closely agreed with the record of the United States Weather Bureau that the observations in the enclosure were discontinued.

At the Hancock Experimental Farm the amount of rainfall was secured from the farm meteorological records, and that for the outlying series of plots was secured from the farm records in 1921 and from rain gauges on each series in 1922 and 1923.

The results of field observations and of moisture determinations indicate that precipitation of less than 0.3 inch coming as an individual shower or as an accumulation over a two- or three-day period has practically no beneficial effect on the crops on these sandy soils. Figures 5 and 6 are, therefore, designed to show the amount and distribution of precipitation, during the growing season, of 0.3 inch or more which fell during a one-, two-, or three-day period. The rainfall on the Coloma fine sand plots is practically identical with that at the Experimental farm. The graphs of the former, therefore, serve also as those of the latter.

RESULTS

Yields

In order that the yields of crops in the four experiments may be easily compared, they have been reduced to average tons and bushels of each crop produced. In computing the average yields of grains, it has been assumed that the grain is that portion of the crop from which the farmer realizes the larger proportion of his cash income. The average yields of the grains, therefore, represent the returns the farmer would have obtained in growing the crops for that purpose during the years over which the various experiments were conducted. These averages are shown in tables 3, 4, 5, and 6.

One of the outstanding facts shown in tables 3 and 4 is that of the extremely low average yield of oats, especially when grown on medium and fine sand. This agrees with the generally accepted belief that oats cannot be grown profitably on the lighter sandy soils.

The average corn yields on these soils are low. Table 3 shows a 7-year average of 6.8, 11.3, and 18.0 bushels per acre for medium sand, fine sand, and sandy loam respectively, whereas table 6 shows a somewhat higher 2-year average of 21.1, 13.2, and 28.7 bushels for the same classes of soil. The marked depressed yield of 13.2 bushels on the fine sand as compared to 21.1 bushels on medium sand is not in keeping with the yields in the other experiments, but

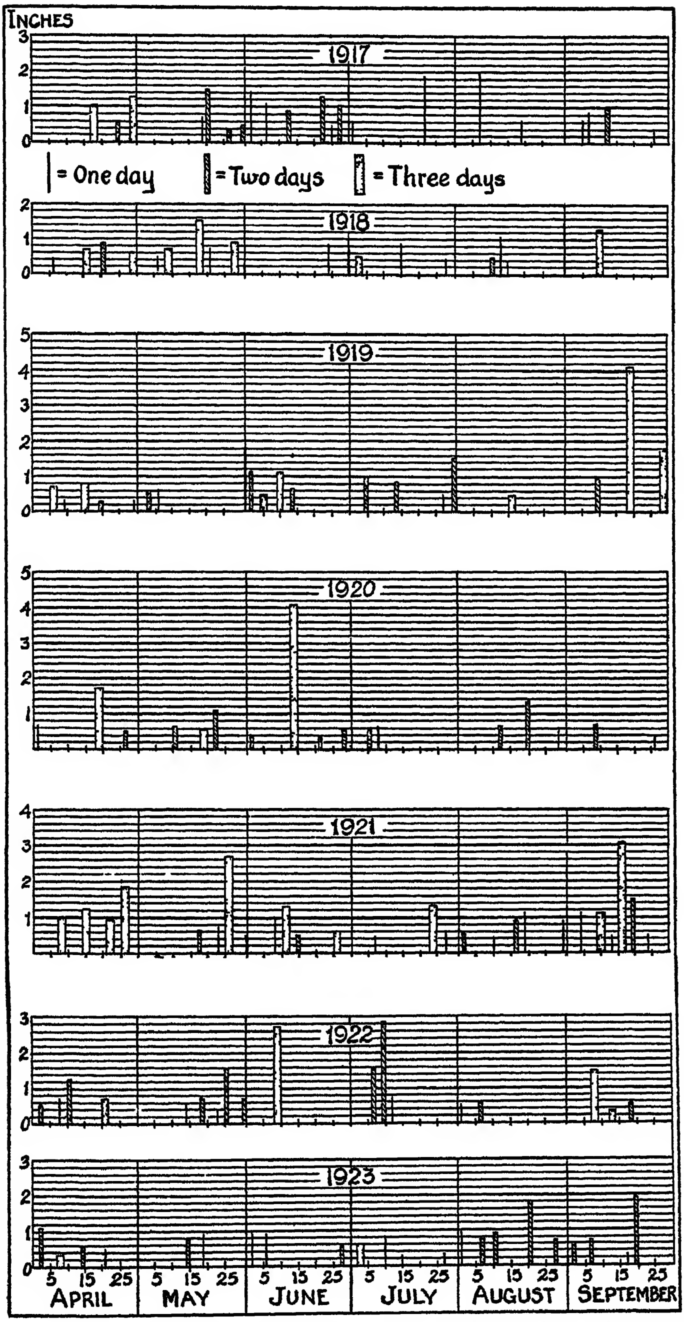

FIG. 5. AMOUNT AND DISTRIBUTION OF RAINFALL OF 0.3 INCH OR MORE OCCURRING WITHIN 1-DAY, 2-DAY, OR 3-DAY PERIODS DURING THE GROWING SEASON AT MADISON 1917–1923

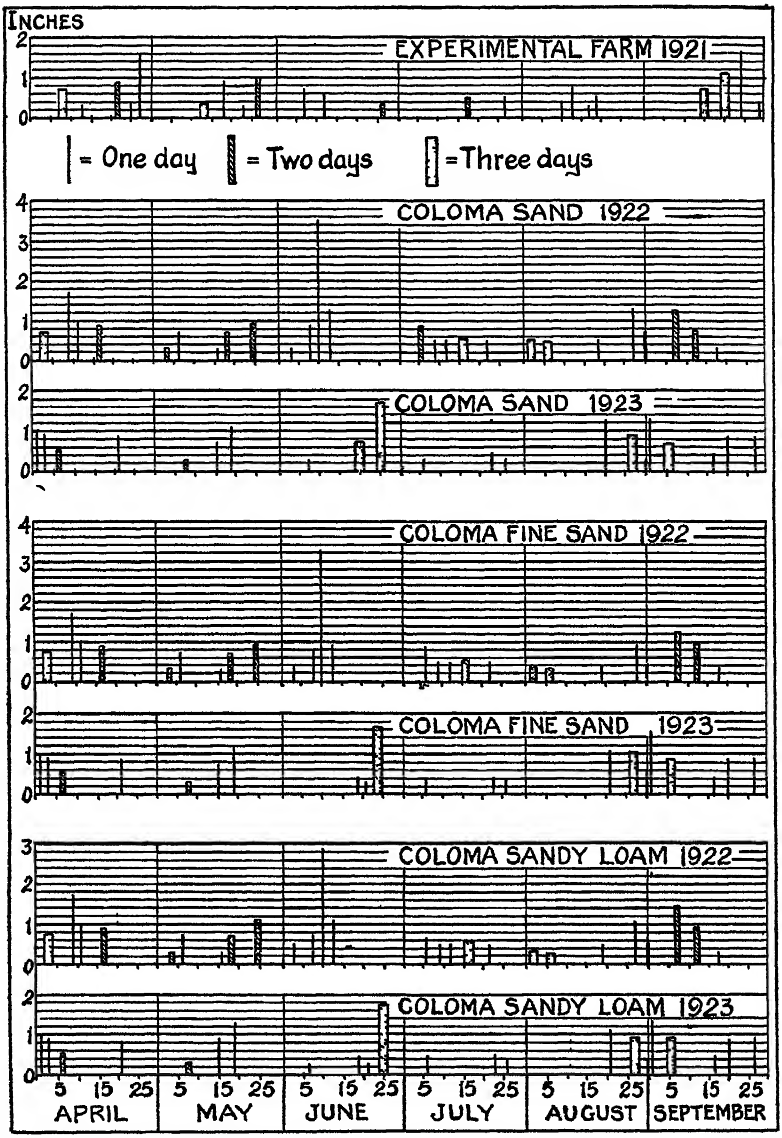

Fig. 6. Amount and Distribution of Rainfall of 0.3 Inch or More Occurring Within 1-Day, 2-Day, or 3-Day Periods During the Growing Season at the Hancock Experimental Farm and the Plots Near Hancock

The rainfall for Coloma fine sand is also the rainfall at the Experimental Farm during 1922 and 1923.

as yet it has been impossible to determine what condition or set of conditions produced it. By selecting the years in which the highest yields of corn were obtained in experiment I, it is found that the medium sand produced a 2-year

TABLE 3

Average yields of corn, oats, soybeans, and clover, from experiment I, grown on medium sand, fine sand, and sandy loam in cylinders 1–27, at Madison 1917–1923

CROP	MEDIUM SAND		FINE SAND		SANDY LOAM	
	Total weight of air-dried material produced on three cylinders from 1917 to 1923 inclusive	Average yearly yield per acre	Total weight of air-dried material produced on three cylinders from 1917 to 1923 inclusive	Average yearly yield per acre	Total weight of air-dried material produced on three cylinders from 1917 to 1923 inclusive	Average yearly yield per acre
	pounds		*pounds*		*pounds*	
Corn 7 years:						
Stover	128,162.5	3.05 T.	112,560.3	2.64 T.	143,489.8	3.42 T.
Grain	9,997.2	6.8 bu.	16,631.3	11 3 bu.	26,483.9	18.0 bu.
Total	138,159.7	3.29 T.	129,191.6	3.07 T.	169,973.7	4.04 T.
Oats 7 years:						
Straw	36,498.7	0.87 T.	41,230.8	0.98 T.	61,429.4	1.46 T.
Grain	2,107.8	3.1 bu.	6,914 5	10.3 bu.	9,471.0	14.4 bu.
Total	38,606.5	0 92 T.	48,145.3	1.15 T.	70,900.4	1.68 T.
Soybeans 6 years:						
Straw	54,741.3	1.52 T.	55,513 5	1.54 T.	59,569.0	1.65 T.
Grain	8,829.2	8.2 bu.	8,068.7	7.4 bu.	9,357.8	8.6 bu.
Total	63,570.5	1.76 T.	63,582.2	1.76 T.	68,926.8	1.91 T.
Clover 1 year:						
Hay	11,562.5	1.92 T.	16,441.8	2.74 T.	14,061.8	2.34 T.
Average pounds produced per acre during seven years	3,949		4,364		5,010	

TABLE 4

Average yields of corn and soybeans from experiment II grown on medium sand, fine sand, and sandy loam at Madison, 1921 and 1923

CROP	MEDIUM SAND		FINE SAND		SANDY LOAM	
	Total weight of air-dried material produced on two cylinders in 1921 and 1923	Average yearly yield per acre	Total weight of air-dried material produced on two cylinders in 1921 and 1923	Average yearly yield per acre	Total weight of air-dried material produced on two cylinders in 1921 and 1923	Average yearly yield per acre
	pounds	*tons*	*pounds*	*tons*	*pounds*	*tons*
Corn 1 year:						
(Stover)	6,202.5	1.55	8,871.6	2.22	13,116.0	3.27
Soybeans 1 year:						
(Hay)	5,444.8	1.36	5,708.6	1.43	7,269.1	1.82
Average pounds produced per acre during two years	2,911.8		3,645.0		5,096.2	

average of 23.8 bushels, whereas the fine sand and sandy loam produced a 3-year average of 26.4 and 42.0 bushels per acre, respectively. On the basis of the 7-year period, these better yields may be expected about 4 out of 10 years. In 1922, in experiment IV, corn made a good yield for ensilage or grain. At 70 cents a bushel the returns from medium sand, fine sand, and sandy loam were $29.40, $18.20, and $39.90 per acre, respectively.

Soybeans as a seed crop, with average yields for 7 years of 8.2, 7.4, and 8.6 bushels per acre (table 3) do not pay. On the other hand, fairly normal

TABLE 5

Average yields of corn, rye, and soybeans from experiment III grown on medium sand, fine sand, and sandy loam in the cylinders at the Hancock Experimental Farm, 1922–1923

CROP	MEDIUM SAND		FINE SAND		SANDY LOAM	
	Total weight of air-dried material produced on two cylinders from 1922–1923	Average yearly yield per acre	Total weight of air-dried material produced on two cylinders from 1922–1923	Average yearly yield per acre	Total weight of air-dried material produced on two cylinders from 1922–1923	Average yearly yield per acre
	pounds		*pounds*		*pounds*	
Corn 2 years.:						
Stover.........	21,787.6	2.72 T.	18,385.2	2.29 T.	24,454.3	3.05 T.
Grain.........	2,335.8	4.15 bu.	4,195.0	7.49 bu.	5,081.5	9.07 bu.
Total.........	24,123.4	3.01 T.	22,580.2	2.82 T.	29,535.8	3.69 T.
Rye, 2 years:						
Straw.........	4,582.7	0.57 T.	3,686.4	0.46 T.	5,291.3	0.66 T.
Grain.........	1,933.3	8.64 bu.	1,464.2	6.53 bu.	1,686.4	7.53 bu.
Total.........	6,516.0	0.81 T.	5,150.6	0.54 T.	6,977.7	0.87 T.
Soybeans 2 years.:						
Hay...........	10,680.5	1.33 T.	15,829.6	1.97 T.	14,080.0	1.76 T.
Grain..........	....	....	....	....	....	....
Total..........	10,680.5	1.33 T.	15,829.6	1.97 T.	14,080.0	1.76 T.
Average pounds produced per acre during two years..	3,443.3		3,630.0		4,230.3	

yields of hay are obtained. In 1922 in experiment IV, sandy loam, produced 17.8 bushels of beans per acre whereas the medium sand and fine sand produced 6.6 and 9.6 bushels, respectively. (Table 6.)

From table 6 it is seen that in 1923 medium red clover made but 0.72, 0.43 and 0.78 tons per acre on medium sand, on fine sand, and on sandy loam, respectively. The season was extremely dry and under more normal moisture conditions the yields would have been more than doubled, as indicated by the yields of 1.92, 2.74, and 2.34 tons per acre in table 3.

A 2-year average of yields of winter rye in table 6 shows that 10.62, 9.37, and 26.16 bushels per acre were grown on medium sand, on fine sand, and on sandy

loam. This crop is one of the most reliable for sandy soils, as it matures sufficiently early to escape the longer periods of drought which frequently occur during July and August.

On the basis of yields, precipitation, texture, and moisture determinations

TABLE 6

Average yields of corn, oats, rye, soybeans, and clover from experiment IV grown on field plots of medium sand, fine sand, and sandy loam near Hancock, 1921–1923

CROP	MEDIUM SAND		FINE SAND		SANDY LOAM	
	Total weight of air-dried material produced on comparable plots 1921–1923	Average yearly yield per acre	Total weight of air-dried material produced on comparable plots 1921–1923	Average yearly yield per acre	Total weight of air-dried material produced on comparable plots 1921–1923	Average yearly yield per acre
	pounds		*pounds*		*pounds*	
Corn, 2 years:						
Stover	7,098	1.77 T.	6,556	1.64 T.	10,516	2.62 T.
Grain	2,960	21.14 bu.	1,850	13.21 bu.	4,020	28.71 bu.
Total	10,058	2.51 T.	8,406	2.10 T.	14,536	3.63 T.
Oats 1 year:						
Straw	1,420	0.37 T.	148	0.04 T.	4,384	1.09 T.
Grain	160	2.50 bu.	60	0.93 bu.	900	14.06 bu.
Total	1,580	0.39 T.	208	0.05 T.	5,284	1.32 T.
Winter rye, 2 years:						
Straw	2,330	0.58 T.	2,630	0.66 T.	7,280	1.82 T.
Grain	1,190	10.62 bu.	1,050	9.37 bu.	2,930	26.16 bu.
Total	3,520	0.88 T.	3,680	0.92 T.	10,210	2.55 T.
Soybeans, 1 year:						
Straw	980	0.46 T.	980	0.49 T.	1,770	0.89 T.
Grain	400	6.66 bu.	580	9.66 bu.	1,070	17.83 bu.
Total	1,380	0.69 T.	1,560	0.78 T.	2,840	1.42 T.
Clover 1 year:						
Hay	1,435	0.72 T.	855	0.43 T.	1,555	0.78 T.
Average pounds produced per acre during three years	2,079		1,712		3,882	

it is possible to discuss some of the factors affecting the supply of moisture to crops in these sandy soils.

Effect of Texture on Utilization of Moisture in Crop Production

On July 26, 1921 a rainfall of 0.58 inch occurred which was recorded on the 27th. Twenty-four hours after the rain had ceased moisture determinations

were made on cultivated corn plots on each soil to determine the depth to which it had penetrated. Table 7 indicates that within 24 hours the effect of the rain was slightly apparent in the 12 to 18 inch depth of medium sand, but was almost wholly confined within the 6 inch depths of fine sand and sandy loam.

August 3, eight days after the rain, another set of samples for moisture determinations were taken. Table 7 indicates that the effect of the rain in the medium and fine sands has disappeared but is evident in the 18 to 30 inch depth in the sandy loam. The increase in moisture in the 24 to 30 inch depth in the sandy loam is 5.12 per cent over that of July 27, an equivalent of 0.45 inch. Penetrating at an observed rate of 4 inches a day, the influence of this rain should have been evident in the 30 to 36 inch depth. Since the observed depth of 4 inches was made wholly within the surface soil, retardation, due to the more compact subsoil and to the demands made on the water by the growing crop, would account for this difference. The results obtained by Harris and Turpin (13) and Burr (8) from investigations with finer textured soils

TABLE 7

Changes in the water content of medium sand, fine sand, and sandy loam at different intervals after a 0.58 inch rain on corn plots

DEPTH	MEDIUM SAND		FINE SAND		SANDY LOAM	
	24 hours	8 days	24 hours	8 days	24 hours	8 days
inches	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
0–6	6.15	2.47	6.03	2.21	7.22	3.50
6–12	3.43	2.89	1.70	1.49	2.71	2.81
12–18	3.01	2.59	1.60	1.43	2.33	2.63
18–24	2.93	2.54	1.30	1.35	3.24	4.85
24–30	3.29	3.13	1.55	1.56	2.64	7.76
30–36	3.31	3.70	2.38	2.01	5.62	5.47
36–40	6.30	5.95	2.80	2.42	6.16	5.63

than those here employed, although not of the same magnitude, are in agreement with those reported above.

The utilization of water falling as rain in supplying the needs of crops growing upon sandy soils of low organic matter content is a function of texture. Its effect may be seen by studying the character and distribution of rainfall throughout any growing season in relation to the yields produced. The season of 1920 in experiment I has been chosen because of the drought in July. The monthly precipitaton for the growing season is as follows: April, 0.43; May, 2.51; June, 5.62; July, 1.39; August, 2.61; and September, 1.12 inches.

The rainfall data for 1920 show that during the growing season there were 9 rains of 0.5 inch or more; 1 in May, 4 in June, 2 in July and 2 in August. The 4 June rains totaled 4.04 inches and fell between the 13th and 16th. According to the work of King (16) on Plainfield sand at Stevens Point, Wisconsin, the medium sand held about one inch, the remainder percolating beyond the reach of the roots of crops. That this loss is permanent is further substantiated by

Grebe (11) who, from his study of the water lifting power of very sandy forest soils, concludes that sands and very fine sands do not lift water above the water table more than 13.1 and 19.7 inches, respectively.

It is also shown in table 7 that water percolates more slowly through fine sand and sandy loam than through medium sand, the rate decreasing with the finer texture. Alway and McDole (1) have shown that 1 inch of water applied to the surface of "sandy land" with an initial moisture content of 4.9 per cent penetrated 10.3 inches at the end of 5 days.

The 2 rains that fell on July 6 to 8, totaled 1.2 inches all of which was held by the soils. A very dry period of 34 days followed, during which 0.01 inch fell on July 30, 31 and August 8, and 0.07 on August 4. On August 12 and 13, 0.64 inch; 20 and 21, 1.37 inches; and 27 to 29, 0.52 inch precipitations occurred. In September, 0.74 inch of the total 1.12 inches for the month fell during the first 9 days. A period of 34 days followed (September 10–October 13) during which 0.01 and 0.37 inch fell on September 19 and 26, respectively.

In the light of the foregoing facts concerning the distribution of rain during the season, a study of the relative utilization of moisture as influenced by texture may be made on the basis of the yields of corn.

The sandy loam gave an increase of 1146.5 pounds per acre over the find sand and of 628.7 pounds over the medium sand. This indicates that the sandy loam is capable of retaining sufficient moisture as a reserve from the heavier rains to supply the crop more adequately with moisture during the intervening periods of light showers.

The fine sand, on the other hand, with its lower water-holding capacity, lost much more water by percolation from the heavier rains. Because the rate of penetration after a 0.5 inch rainfall is not much greater than that in the sandy loam, but nearly one-third less than in the medium sand, the fine sand has not been able to utilize the water from the lighter showers so economically as the medium sand.

In experiment II the rainfall records for 1921 show that the precipitation for the growing season is as follows: April, 5.16; May, 5.13; June, 3.52; July, 2.46; August, 3.97; and September, 7.9 inches—a total of 28.14 inches. This is exceptionally high. The distribution, with the exception of the first 22 days of July, is almost ideal. (Fig. 5.) Under these conditions the influence of texture on the utilization of moisture as indicated by yields in table 4 is shown in the order of medium sand, 1.55; fine sand, 2.22; and sandy loam, 3.27 tons of corn per acre.

During the 1923 growing season 2.59 inches of rain fell in April, 1.90 in May, 3.05 in June, 2.28 in July, 5.59 in August, and 4.36 in September—a total of 19.77 inches. Because of the light amount of precipitation in May, the soils were somewhat deficient in moisture at the time the soybeans were planted. In June, 1.92 of the 3.05 inches fell during the first 6 days, the remaining 1.13 inches falling as light showers mostly between the 25th and 28th. Another period of light rainfall occurred between July 11 and 31. The August dis-

tribution was good and so continued until September 21, followed by a dry period of 22 days. Under these seasonal conditions the medium sand utilized its moisture as well as the fine sand, which is indicated in table 4 by the yields of 1.36 and 1.43 tons of soybean hay per acre, respectively. The sandy loam, with its inability to utilize the light rains of June and July failed to give the larger proportionate yield that would have been possible under a more uniform distribution of heavier rains, as indicated by its yield of 1.82 tons per acre.

Many similar comparisons of the results of the cylinder experiments agree so closely with those above that no further comment will be made on them in this connection.

The rainfall during the growing season for oats in 1921 was unfavorable on the plots in experiment IV. Figure 6 shows that the distribution of rain in April was characterized by light showers with a 1.6 inch rain on the 27th, following which no rain fell for 14 days. From May 12 to 27, 2.71 inches fell in 6 well distributed showers. During June, 0.7 and 0.6 inches fell on the 7th and 12th, and 0.35 on the 26th and 27th, making a total of only 1.65 inches for the month. The July precipitation of 1.48 inches was less well distributed in four showers than that of June.

The effect of texture in utilizing moisture for the oats crop is shown in table 6. The sandy loam was able to hold within reach of the roots of the oats a sufficient portion of the 1.6 inches of rain in April and the 0.97 inch and 1.05 inches falling May 18, 26, and 27, to produce a yield greater than on the medium and fine sands. The effect of the marked infrequency of light showers in May and June is reflected by the low yield on the medium sand. The fine sand, on the other hand, unable to use efficiently the water of the few light showers and that of the heavier rains, produced the least. A comparison of the heights of the oats on the different soils on June 28, is shown in plate 2.

The season of 1922 was marked by a total and well distributed precipitation of 23.24 inches as compared to the 16.17 inches of 1921. A study of the rainfall distribution on the medium sand plots in figure 6 reveals a decided grouping of rains during April and May with 4 rains during the first 15 days in June, 1 of which is 3.56 inches on the 10th and the other 1.25 inches on the 13th. A period of 22 days follows without rain until May 6 following which well distributed rains of over 0.5 inch occur. Three groups of rains, which are well distributed, occur in August, and in September two groups occur during the first two weeks.

Under these conditions, 6960, 5250, and 10420 pounds of corn; 1380, 1560, and 2840 pounds of soybeans; and 2100, 2960, and 7170 pounds of rye were produced per acre on the medium sand, on the fine sand, and on the sandy loam respectively. These yields indicate that the heavy rains in April and June, were sufficiently held by the sandy loam to supply moisture to the corn crop during its vigorous growing period in July and August, whereas the lighter showers of July and August were better utilized by the medium sand than by the fine sand.

The fine sand showed but little difference from the medium sand in its supply of moisture to soybeans. The sandy loam, however, responds as in the case of the corn crop.

Rye made its maximum growth in May and June. The grouping of the rains in May and June was such that a good portion of them falling during each period was lost for the crop by percolation from the medium sand, less from the fine sand, and the least, if any, from the sandy loam. Consequently during the 22-day period of no rain in June and July, the supply of moisture in the medium sand was reduced below that of the fine sand in the root zone and was reflected in the aforementioned yields.

During the growing season of 1923 but 14.9 inches of rain fell. Its distribution is characterized by long periods of very little or no precipitation and a small number of light showers under 0.5 inch.

The effect of texture on the supply of moisture under these conditions is shown by the yields obtained. Corn produced 3090, 3156, and 4106; and rye 1420, 1620, and 3040 pounds per acre on medium sand, fine sand, and sandy loam, respectively. There is but little difference between the effect of the fine sand and medium sand in their utilization of water, especially in the case of the shallower rooting rye. The former, however, gave an increase over the latter of 200 pounds of rye.

The corn crop as it appeared on August 4 is shown in plate 3.

When the average number of pounds per acre of all crops produced during the three years is considered, it is evident that the medium and fine sands are similar in their ability to supply water to the crops, the former producing slightly more than the latter. The sandy loam, however, is most efficient, as shown in table 6.

The assemblage of the yields of the various crops produced on all of the cylinders and plots shows the average weight of dry matter produced per acre on medium sand, on fine sand, and on sandy loam to be 3327, 3588, and 4668 pounds, respectively. The difference between the productive capacity of the medium and fine sand is small. This shows that from the standpoint of production their value is nearly identical. It would be entirely feasible, therefore, in a classification in which productiveness is considered essential, to group these two classes of soils together as one.

The effect of texture on the utilization of moisture is shown further by a study of the moisture content of the soil in relation to the amount and character of distribution of the rainfall.

On July 5, 1922, moisture determinstions of each class of soil were made to a depth of 2 feet. Prior to this date a 28-day period occurred which was characterized by a few heavy rains; following it, a 23-day period marked by frequent rather light rains occurred. The precipitations during the two periods are given in table 8.

Moisture determinations were made for each class of soils on June 6, the

beginning of the first period, and on July 29, the close of the second period. These results and also those for July 5 are shown in table 9.

After receiving 5.76 inches of rain, the medium sand contained 0.17 inch *less* water on July 5 than on June 6. But at the close of the second period on July 29, after receiving 2.95 inches, it contained 0.05 inch *more* water than on July 5.

The fine sand received 5.13 inches during the first priod, at the close of which it contained 0.41 inch *less* water than at the beginning. On the other hand, after receiving 2.96 inches throughout the second period it contained 0.25 inch *more* water than on July 5.

TABLE 8

Precipitation on the medium sand, fine sand, and sandy loam plots June 6 to July 29, 1922

28-DAY PERIOD				23-DAY PERIOD			
Date	Medium sand	Fine sand	Sandy loam	Date	Medium sand	Fine sand	Sandy loam
	inches	*inches*	*inches*		*inches*	*inches*	*inches*
June 8	0.87	0.78	0.76	July 6	0.83	0.86	0.66
June 10	3.56	3.25	2.88	July 9	0.51	0.51	0.52
June 13	1.25	0.93	1.10	July 12	0.52	0.51	0.52
June 27	0.08	0.17	0.09	July 15	0.03	0.03	0.04
				July 16	0.04	0.05	0.05
				July 17	0.51	0.50	0.51
				July 22	0.51	0.50	0.51
Totals	5.76	5.13	4.83		2.95	2.96	2.81

TABLE 9

Moisture content of the first 2 feet of medium sand, fine sand, and sandy loam plots on the dates indicated

DATE	MEDIUM SAND	FINE SAND	SANDY LOAM
	inches	*inches*	*inches*
June 6	0.80	0.99	1.17
July 5	0.63	0.58	1.12
July 29	0.68	0.83	0.72

This shows that the medium sand and fine sand contain more water in the first 2 feet when about one-half the rainfall is distributed as light rains, than when it comes as infrequent and heavier rains. The sandy loam, however, utilizes the heavier, less frequent rains to better advantage than the lighter, more frequent rains.

SUMMARY

The marked depression in yields of crops on sandy soils during seasons of limited or poorly distributed rainfall has long been commonly noted. The greater portion of these soils is included in the medium sand, fine sand, and

sandy loam classes established by the Bureau of Soils of the United States Department of Agriculture. The results of numerous investigations would lead to the conclusion that there might be marked differences among these soil classes with respect to their ability to supply moisture to crops. It seemed desirable, therefore, to make a study of the moisture relationships of these soils in order to determine to what degree their moisture content, under varying seasonal distribution of rainfall, becomes a limiting factor in crop production.

1. The study was conducted as four experiments on field plots and on cylinders of each class of soil under similar and under somewhat different climatic conditions.

2. The soils used were Coloma sand, Coloma fine sand, and Coloma sandy loam, all having a low organic matter content.

3. Appropriate fertilizers were applied in amounts adequate to supply the needs of the crops so that the moisture supply, as determined by the texture of the soil, would be the limiting factor in crop production.

4. Corn, oats, clover, rye, and soybeans were the crops employed.

5. Over 1200 moisture determinations were made on the plots in experiment IV.

6. Precipitation data at Madison were secured from the records of the United States Weather Bureau, and those at Hancock, from the Experiment Farm records and from outlying rain gauges.

7. The oats crop is not adapted to the sandy soils employed.

8. Corn for ensilage can be produced on the three classes of soil, but when it is grown for grain, should be confined to sandy loam for more profitable yields.

9. Profitable yields of corn, based on the 7 years' work in experiment I, may be expected 4 out of 10 years.

10. Rye is the small grain crop best adapted to these sandy soils.

11. As a forage crop, soybeans yield well on the three soil classes. More profitable yields of seed are grown on sandy loam, as indicated by the yields from experiment IV in 1922 when medium sand and fine sand produced 6.6 and 9.6 bushels per acre, respectively, whereas sandy loam gave a yield of 17.8 bushels.

12. The penetration of moisture on cultivated corn plots 24 hours after a 0.58 inch rain is into the 12 to 18 inch depth of medium sand, but is almost wholly confined to the 6 inch depths of fine sand and sandy loam. Eight days after the rain, its effect in the medium and fine sands has disappeared but is evident in the 18 to 30 inch depth of sandy loam.

13. Medium sand supplies crops with more moisture from light rains and showers than does fine sand or sandy loam when the precipitation comes at a time when the initial moisture content of the soils is low. The greater water-holding capacity of sandy loam enables it to store a sufficient supply from the heavier rains to produce the largest yields under the type of seasons during this investigation.

14. The difference between the productive capacities of medium and fine sand, as determined by their ability to meet the water requirements of crops over periods of 2 to 7 years, is negligible, and suggests the feasibility of grouping them together as one class in any system of classification in which productiveness is considered an essential factor.

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PLATE 1

FIG. 1. View of medium sand plots (100 series) toward the southwest corner.
FIG. 2. View of fine sand plots (200 series). Gentle slope from road toward camera.
FIG. 3. View of sandy loam plots (300 series). Gentle slope from road toward camera.

FIG. 1

FIG. 2

PLATE 2

FIG. 1. Oats on medium sand plots, June 28, 1921.
FIG. 2. Oats on fine sand plots, June 28, 1921
FIG. 3. Oats on sandy loam plots, June 28, 1921

Рис 1

Рис 2

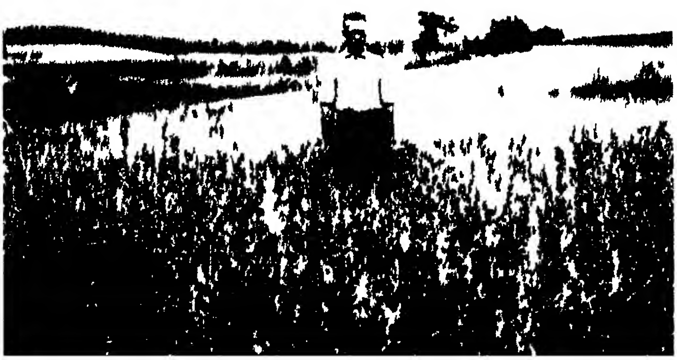

PLATE 3

FIG. 1. Corn on medium sand plots, August 4, 1923.
FIG. 2. Corn on fine sand plots, August 4, 1923.
FIG. 3. Corn on sandy loam plots, August 4, 1923.

Fig. 1

Fig. 2

Fig. 3

THE BACTERIAL TYPES OCCURRING IN FROZEN SOIL

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INTRODUCTION

In the course of a previous investigation by the writer (8) conducted during the season 1923–24, examinations were made of the numbers of bacteria, actinomycetes, fungi, and protozoa occurring at different depths in soil throughout the course of the winter months. Quantitative determinations were conducted at 2- to 3-week intervals from November 14 to April 21.

Although it was found that frozen soil under winter conditions such as prevail in Eastern Canada is capable of harbouring large numbers of the microörganisms studied, the results strengthened the belief that they are in a dormant state under conditions of frost.

The numbers of bacteria, developing on albumin agar plates incubated for 12 days at 20°C., remained high throughout the winter, very little variation from the count on November 14 being recorded throughout the period of frost. Although the numbers were not lessened when the soil actually became frozen, no phenomenal increases were observed which would lend support to the theory of stimulation through frost to which other observers, notably Conn (2, 3, 4) and Brown and Smith (1) would ascribe increases reported by them. Only with the advent of mild conditions was a noticeable increase in numbers observed. Parallel determinations by the direct microscopic method of Conn (7) gave no fluctuations which could be ascribed to anything apart from the high experimental error inherent in such a method. From a qualitative standpoint, the method is of greater value when some idea of the types and arrangement of the bacteria is given. In frozen soil, short rods comprised the great majority of the bacteria observed, present for the most part as single cells, the average number of individuals in each group varying from 1.33 to 1.75 during the period.

Actinomycetes, as determined by the plate method, appeared to remain more or less stationary in numbers, forming, however, a considerable proportion of the colonies found on the albumin agar plates. At a depth of 2 inches they comprised 27.2 per cent of the total bacterial colonies; at 6 inches, 34.7 per cent; and at 10 inches, 39.6 per cent.

The figures for the fungi revealed the only instance where marked increases throughout the season were recorded. Plate counts made on an agar medium

of pH = 4.0 as described by Waksman (9), showed regularly increasing numbers throughout the period of frost at the three depths studied. The significance of the plate count with fungi is different from that with bacteria and is probably related to the ability of the former to produce multiple spores. For that reason and also in the light of tests made with the other organisms, the increased counts obtained are taken to indicate increased spore production rather than enhanced vegetative activity.

Protozoa, as determined by the dilution method, decreased in numbers at the upper level throughout the frost period. At lower depths no changes were observed. After thawing at the end of winter, marked increases were found at the 2- and 6-inch levels.

With the object of gaining some insight as to the possible development of a special "winter" group of bacteria, which would tend to have a lower optimum growth temperature than a hypothetical "summer" group, determinations were made throughout the winter not only of bacteria developing at 20°, but of those developing at 3° and at 37°C. The results obtained pointed against the existence of a group of "winter" bacteria. The 20° counts were in all cases much in excess of those at 37° or at 3°, the great difference holding not only for soil in the late fall, but equally so in the case of winter soils. On the basis of the theory of special "winter" bacteria it would be expected that during the course of the cold season a change would be observed in the proportion of bacteria developing at the different temperatures. The proportion of those developing at 37° to those at 20° would be expected to decrease, whereas those developing at 3° would be proportionately more numerous. The data, however, show no downward trend at 37°, and on the other hand, no upward tendency of organisms capable of growth at 3°. The only actual marked increase in the numbers of colonies on low temperature plates occurred at the end of the period of frost. Most of the bacteria in winter soils seem incapable of development at low temperature, and further, it would seem that organisms actually capable of growth at low temperature develop, not under conditions of frost, but in unfrozen or thawed soil. In further support of this view is the fact that the only instance of increasing counts of organisms on low temperature plates occurred at 10 inches, at which depth the soil remained unfrozen.

In the course of a special study of bacteria capable of growth at low temperature (3°C.) isolated from the soil after it had been frozen for 10 weeks at 2 inches and for over seven weeks at 6 inches, 20 presumably distinct species were isolated. Of these only 1 showed better growth at 3° than at 20°, 3 showed approximately equal growth at the two temperatures, whereas the remaining 16 species all grew noticeably better at 20° than at 3°. The most abundant species belong to this last group. The results indicate that the bacteria of frozen soil are to be regarded as cold-enduring rather than psychrophilic in the true sense.

FURTHER STUDY OF BACTERIAL TYPES

During the winter 1924–25 further studies were made of frozen soil from the same field, which had in the meantime grown a crop of corn followed by fall plowing. It was planned to continue a study of the types occurring in frozen soil with emphasis laid also on their quantitative relationships.

Samples at 2-, 6-, and 10-inch depths were taken March 13, 1925 toward the end of the period of frost, at which time any possible adjustment of types

TABLE 1

Bacteria found in frozen soil, March 13, 1925

MEDIUM	INCUBATION TEMPERATURE	2-INCH	6-INCH	10-INCH
	°C.			
Albumin agar	37	6,800,000	6,900,000	1,450,000
Albumin agar	20	33,900,000	25,900,000	6,800,000
Albumin agar	3	2,030,000	1,570,000	550,000
Soil extract agar	3	2,600,000	1,730,000	380,000
Nutrient agar	3	6,080,000	6,500,000	1,330,000

TABLE 2

Bacterial types in frozen soil developing on albumin agar at 20° and 3°C.

TYPES	20°C.			3°C.		
	Cultures isolated		Approximate number per gram soil	Cultures isolated		Approximate number per gram soil
		per cent			*per cent*	
Total	206	100.0		80	100	0
Actinomycetes	62	30.1	9,000,000	0	0	0
Bacteria	144	69.9	20,900,000	80	100	1,800,000
Micrococci (Slowly or non-liquefying)	4	2.0	600,000	0	0	0
Short rods (Slowly or non-liquefying	89	43.2	12,900,000	72	90	1,600,000
Short rods (Rapid liquefiers)	5	2.4	700,000	0	0	0
Medium to large rods (slowly or non-liquefying	26	12.6	3,800,000	0	0	0
Medium to large rods (Rapid liquefiers)	4	2.0	600,000	0	0	0
Unclassified	16	7.8	2,300,000	8	10	200,000

through frost would have been accomplished. Triplicate plates were made of all dilutions, and parallel series of plates were prepared for incubation at 37°, 20°, and 3°C. The medium used was the albumin agar of Brown as modified by Waksman (10), though in addition soil extract agar and nutrient agar were used for plates incubated at 3°. The results of the quantitative tests are given in table 1.

As was found the previous winter the number of organisms appearing at 20° was greatly in excess of the 3° count, even after more than 2 months continuous frost. Most of the bacteria of frozen soil appear to be incapable of development at low temperature.

FREQUENCY OF DIFFERENT BACTERIAL TYPES IN FROZEN SOIL

A comparison was made of the frequency of the different types of organisms developing on albumin agar at 20° and at 3° respectively. For this purpose the soil at 2 and 6 inches only was considered, the sample at 10 inches being below the frost line.

Typical plates from the 2- and 6-inch sets were selected, and all colonies transferred for pure culture study. Plates showing rather fewer than 100 colonies were chosen, although in cases where rather more were present one-half of the plate only was used for isolating. Determinations of morphology and certain cultural characteristics were made, though in a number of cases where transfers showed no growth, the organisms could not, in consequence, be classified. The data presented in table 2 represent averages for the 2- and 6-inch depths.

Of the bacteria in winter soils, the short rods, non-spore-forming and with little or no liquefying power, appear to form the largest group. This type, also appears to represent most of the bacteria capable of low temperature growth (3°C.). Short rods of the rapidly liquefying type are numerically much less important. Rods of larger size are likewise less important, and belong to the class which is much inhibited by low temperature. Micrococci form a numerically insignificant group.

Actinomycetes comprise an important group of organisms, a group which under moderate temperature conditions may be physiologically as well as numerically important. On the plates at 3°C. however, they were absent, and it appears reasonable to assume that even before the soil is in a frozen state they lose their activity with the lowering temperature.

Although the medium, albumin agar, was different from that used by Conn (5) who employed gelatin in the course of an investigation into bacterial types in soil, there is a general agreement with the relative abundance of the various groups reported. Conn found that the non-sporulating, slowly or non-liquefying short rods comprised the largest group (40–75 per cent), with Actinomycetes next in point of abundance (12–50 per cent). Non-spore-forming, liquefying short rods as well as spore-formers of the *B. subtilis* group were under 10 per cent, whereas but few micrococci were observed. It would appear that these organisms from frozen soil represent a "characteristic soil flora" and the belief is further strengthened that no change to a "winter" group follows prolonged frost, the soil microflora being rather dormant.

STUDY OF ORGANISMS DEVELOPING ON 3° PLATES

A more detailed study was made of the characteristics as well as of the relative frequency of the species appearing on the 3° plates of albumin agar, of soil extract agar, and of nutrient agar. Typical plates were selected from the 2- and 6-inch samples from which colonies were subcultured for pure culture study. In certain cases where appearance and low-power examination pointed to identical types, all were not subcultured but merely recorded.

TABLE 3

Characteristics and frequency of bacterial species from frozen soil developing at 3°C. on nutrient agar (average of 2- and 6-inch depths)

LABORATORY NUMBER	APPROXIMATE NUMBER PER GRAM SOIL	FORM	SPORES	MOTILITY	GRAM STAIN	CHROMOGENESIS ON NUTRIENT AGAR	GELATIN LIQUEFACTION	MILK: Acid	MILK: Coagulation	MILK: Peptonization	AMMONIA IN NUTRIENT BROTH	INDOL	NITRATES REDUCED	DEXTROSE	LACTOSE	SACCHAROSE
A7	3,380,000	Short rod	–	–	–	–	sl.	–	–	–	–	–	–	– –	– –	– –
C7	1,300,000	Short rod	–	+	–	–	–	–	–	–	sl.	–	+	– –	– –	– –
C8	380,000	Short rod	–	sl.	–	Brown	–	–	–	–	+	–	+	+ –	– –	– –
C13	100,000	Short rod	–	–	–	–	–	–	–	–	+	–	+	+ –	– –	– –
C14	100,000	Slender rod	–	+	–	Yellow-brown	–	–	–	–	sl.	–	+	– –	– –	– –
A5	60,000	Short rod	–	+	–	–	sl.	–	+	+	+	–	–	+ –	– –	– –
C2	60,000	Slender rod	–	+	–	Pink	+	–	–	–	sl.	–	–	– –	– –	– –
C11	40,000	Large rod	+	–	+	–	sl.	–	–	–	+	–	+	– –	– –	– –
B101	40,000	Medium rod	–	+	–	Brown	+	–	–	–	–	–	–	– –	– –	– –
C5	20,000	Coccus	–	–	+	Yellow	–	–	–	–	–	–	+	+ –	+ –	– –
C6	20,000	Coccus	–	–	–	Brown	–	–	–	–	–	–	+	+ –	– –	– –
C12	20,000	Short rod	–	–	–	–	sl.	–	–	+	+	–	–	+ –	– –	– –
A1	20,000	Short rod	–	–	–	–	sl	–	–	–	–	–	–	– –	– –	– –
B4	20,000	Medium rod	–	–	–	–	–	–	–	–	–	–	–	– –	– –	– –
C106	20,000	Large rod	+	+	–	–	sl.	–	–	–	+	–	+	– –	– –	– –
CX3	20,000	Slender rod	–	+	–	Yellow	sl.	–	–	–	–	–	–	– –	– –	– –

+ positive, – negative, sl. slight, + – acid but no gas, – – no acid or gas.

Over 100 cultures were studied. This number was reduced by cultural and morphological tests to 23 that could be presumed to be distinct species. Of these, 16 appeared on the nutrient agar, 7 on albumin agar, and 6 on soil-extract agar, identical species appearing in some cases on two or on all three media. As the nutrient agar gave not only the highest total count but also exhibited the greatest number of types, the determinations in table 3 refer to this medium. The data refer to low temperature observations, all cultures

being kept at 3°C. for 15 days—though gelatine and milk tubes were kept 4 weeks—before final observations were made.

In classifying the cultures, it was frequently found that certain strains, although macroscopically and microscopically similar, differed in some characteristics from the majority of the type. These differences were generally with respect to nitrate reduction, or to acid or ammonia production, and were not considered sufficiently distinctive for separate classification. The short rod forms, on the other hand, showed in many cases a similar microscopic appearance both as to size and grouping. The types given in the table, however, showed macroscopic as well as biochemical differences which appeared to warrant specific distinction.

The great majority of the bacteria growing at 3°C. on nutrient agar were found to be short rods which appeared usually as punctiform or small lens-shaped colonies. These were non-sporulating bacteria, 0.5 to 1.4μ long, 0.3 to 0.5μ wide, growing singly or in pairs, chains never having been observed. Another group composed of slender rods, 1 to 2.5μ long, 0.3μ wide, the colonies of which were brown to yellow in color, was much less numerous than the short rods. The larger rods and micrococci formed even less numerous groups.

A very limited number of types appeared to predominate on the 3° plates, the overwhelming majority of the colonies being representatives of but two types. The most abundant organism (A7), comprising more than half the colonies, appears to correspond to the most abundant type of the non-spore-forming organisms described by Conn (6), namely the non-chromogenic, slowly liquefying type of "slow growers." Although our cultures were all kept at 3°C., the characteristics, as far as determined, appear similar to this type. Our second type in point of abundance, incapable of liquefaction, likewise appears to coincide with the non-chromogenic, non-liquefying type of Conn which appeared as the second most numerous type, the reduction of nitrates being the only apparent point of difference. This feature is to be regarded, however, as somewhat variable.

As all the types described above grew rather better (some much better) at 20° than at 3°, none of the cultures represent truly psychrophilic organisms. It would appear rather that the bacteria of frozen soil, even those capable of low temperature growth, represent types which are common to soil at other seasons rather than a distinct winter microflora.

SUMMARY

A study was made of bacterial types in field soil which had been frozen for more than two months.

Determinations were made of the frequency of various types developing on albumin agar plates at 20° and at 3° respectively. Apart from Actinomycetes which did not develop at the low temperature, the number of colonies appearing at 3° was less than 10 per cent of those at 20°, most of the bacteria of frozen soil being incapable of low temperature growth.

At 20° the most abundant type was the group of non-sporulating short rods, non-liquefying or slowly liquefying, and the next most abundant group was that of Actinomycetes. Rapidly liquefying rods and micrococci were found to be numerically unimportant. At 3° the non-liquefying or slowly liquefying short rods formed a higher proportion of the bacterial colonies, the other groups showing even less capability for low temperature growth than these forms.

The microflora of frozen soils does not appear to exhibit characteristics different from that of other seasons.

Sixteen type species, isolated from nutrient agar plates at 3°C. have been described, as well as their approximate frequency. Two types predominate —both non-sporulating short rods—one slowly liquefying, one non-liquefying, and appear to be representative soil types of other seasons which develop better at more moderate temperatures.

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THE PRODUCTION AND USE OF SULFATE IN HUMID AND ARID SOILS AS AFFECTED BY CROPPING AND SULFUR TREATMENTS[1]

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The application of elemental sulfur to different types of soils has produced varied and non-uniform results. Crop response from applications of sulfur does not necessarily vary as the total amount of sulfur in the soil. In fact, a determination of the total soluble sulfate at any one time does not seem to be an index of the result that can be expected from sulfur fertilization.

It is generally believed that sulfur needed in the nutrition of the plant is taken up in the sulfate form, and the indirect effects from the use of elemental sulfur in making soluble certain other plant-food elements, such as calcium, potassium, and phosphorus, also depend upon its oxidation in the soil to sulfate. Whatever may be the direct action of sulfur upon the soil, it seems quite certain that the production of a suitable supply of sulfate throughout a considerable part of the growing season, either from the soil supply, or from that added as a fertilizer, is essential for plant growth.

A great many papers on sulfur in its relation to agriculture have been published, and since the data up to 1922 have been well summarized by Joffe (8) it appears unnecessary to include a general review of the literature on the subject in this paper. Most investigations on sulfur oxidation have been with uncropped soils; some have been with soils under crop; but a careful survey of the literature fails to reveal any investigations which have been comparative on cropped and uncropped soils of different reaction and of known response to field applications of sulfur.

In the light of our present knowledge of the relations of soils and crops it appears reasonable to believe that sulfate production and accumulation in a cropped soil might be different from that in the same soil when fallowed, and that the crop might not affect all soils alike.

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OBJECT OF THIS INVESTIGATION

This research was planned to study the effect of the crop on sulfate production in different soils, the effect of such sulfate on soil reaction, on crop growth, and on percentage of sulfur in the crop. As a secondary consideration some data have been secured relative to the recuperative powers of the various soils studied for sulfate after a depletion has taken place as the result of cropping.

EXPERIMENTAL

Soils

The soils used in this study include: a sandy loam from Vale, Oregon, which has not responded to sulfur fertilizers; a medium sand from Redmond, Oregon, which has produced from $\frac{1}{3}$ to $\frac{1}{2}$ more alfalfa as a result of sulfur treatments; Eldon Silt Loam from Missouri, which has given some response to sulfur treatments; and Putnam Silt Loam from Northern Missouri, which has shown no

TABLE 1

Determination of total sulfur, of sulfate sulfur, and of acidity in the different soils at beginning of the experiment

SOILS	TOTAL AMOUNT OF SULFUR PER 2,000,000 POUNDS SOIL	SULFATE SULFUR	pH	LIME REQUIREMENT, TRUOG METHOD
	pounds	*p.p.m.*		
Vale sandy loam	1096	47	7.4	None
Redmond medium sand	646	21	7.0	None
Eldon silt loam	440	6	6.0	Medium
Putnam silt loam	1130	10	5.7	Strong

indication of needing sulfur fertilizer treatments. The sulfur conditons of these soils are summarized in table 1. It will be noticed that the Vale and Putnam soils are both high in total sulfur but that they are extremely different in pH and are representative, one of the semi-arid and the other of the humid section. The Redmond soil and Eldon soil are both low in total sulfur, have a smaller range in pH, and represent soils one from the semi-arid and the other from a humid section, both of which have responded to sulfur treatments.

Methods

Weighed amounts of each of these soils were placed in gallon jars and five applications of each of the following were made to each soil: check, sulfur 150 pounds per acre, sulfur 500 pounds per acre; triplicate treatments with $CaCO_3$ plus 150 pounds of sulfur per acre were made to additional jars of the Eldon and Putnam soils.

The treatments having been mixed thoroughly with the soil which was then compacted to approach field conditions, the jars were placed in the green-

house. One series, including a jar of each treatment and soil, was kept fallow and the remainder were seeded to soybeans. All jars were kept at approximately optimum moisture with distilled water throughout the period of study. At the end of 38 days one series was harvested, the roots were carefully removed and soil samples taken for sulfate and pH determination. The total crop was dried, the yield secured, and determinations were made of the total sulfur content.

The fallowed jars were sampled at the same time, a soil auger was used and the hole was filled later with surface soil. The location of the borings were recorded in order to avoid sampling in the same place at a later date.

At the time of taking down the first series of jars it became apparent that the soybean crop would neither give the growth desired nor continue growing long enough for the purposes of the experiment, therefore, alfalfa was seeded with the soybeans on the remaining cropped jars. At the end of 77 days from the beginning of the experiment, a second set of jars was taken down, and at the end of 120 days a third set was harvested and sampled. The same procedure in sampling, crop removal, and analysis was followed as at the end of the first period.

Hydrogen-ion determinations were made from 1–2 water extracts; the colorimetric method of Gillespie (3) being employed. Sulfate determinations were made from 1–5 water extracts, 10 per cent aluminum chloride being used as a flocculant. The sulfate sulfur was then determined by the turbidity method of Schreiner and Failyer (9). A "Campbell-Hurley" colorimeter was used and uniform light conditions were insured by making the comparisons at night and reflecting light with a desk lamp from white blotting paper located a uniform distance from the reflector. Total sulfur in the crop was determined by a modification of the method proposed by Wolcoff (14) for soils. Total sulfur in soils was determined by fusion with sodium carbonate, a modification of the Hillebrand (5) method being employed.

RESULTS

A uniform stand of soybeans and alfalfa was secured and although considerable difference was noted in the crop growth when different soils were compared, there was little consistent variation in any soil as a result of sulfur treatments. This was true even with the Redmond soil which has responded to field applications of this element. Such a condition was not unexpected, since crop growth secured under the limited time of this experiment was not enough to deplete the soil of the natural stored supply of sulfate.

Effect of Sulfur Applications to Soil on Sulfur Content of Crops

The pH and the sulfur present in the crop for the various periods are recorded in table 2, and the sulfate sulfur in soil and crop for the same periods, in table 3. It will be noticed that for any one soil the percentage of sulfur in crops

increases almost directly with the sulfur applications and the consequent increase in sulfate. When different soils are compared, however, the sulfur content in the crops does not increase with an increase in the soluble sulfur content of the soil. In some cases, however, because of the larger yield secured, the total weight of sulfur absorbed by each jar increases with a larger sulfate content in the soil.

The results secured at the end of the first period are of most value in studying this condition because of the fact that all jars had a uniform stand of soybeans with no alfalfa. In figure 1 the sulfate sulfur, pH and percentage of sulfur in the crop on soils treated with 150 pounds of sulfur per acre, are compared

TABLE 2

Effect of H-ion concentration of soil on the percentage of sulfur in crop

SOIL*	After 38 days		After 77 days		After 120 days	
	pH	Sulfur in crop	pH	Sulfur in crop	pH	Sulfur in crop
		per cent		*per cent*		*per cent*
Vale—X	7.3	0.262	7.4	0.250	7.5	0.283
Sulfur 150	7.2	0.302	7.2	0.336	7.3	0.317
Sulfur 500	7.0	0.324	7.0	0.348	7.0	0.363
Redmond—X	6.9	0.278	7.0	0.200	7.0	0.241
Sulfur 150	6.7	0.304	6.8	0.232	6.8	0.333
Sulfur 500	6.5	0.388	6.5	0.438	6.6	0.441
Eldon—X	5.5	0.280	5.8	0.298	5.9	0.265
Sulfur 150	5.3	0.316	5.5	0.340	5.7	0.509
Sulfur 500	4.9	0.340	5.3	0.516	5.4	0.895
$CaCO_3$ 3000	6.8	0.302			6.8	0.399
$CaCO_3$ 3000, Sulfur 150	6.6	0.346			6.7	0.398
Putnam—X	5.6	0.316	5.7	0.258	5.7	0.296
Sulfur 150	5.3	0.326	5.4	0.408	5.5	0.381
Sulfur 500	4.8	0.420	4.9	0.580	5.3	0.762

* Treatments are recorded as pounds per acre.

for the various soils. It will be seen when any treatment for the various soils is compared, that the percentage of sulfur in the crop has no tendency to increase with an increase in the soluble sulfate in the soil, but is very closely correlated with increased acidity. With the exception of the Putnam silt loam there is a decided increase in the percentage sulfur in the crop with a decrease in pH value. The crops from the Putnam jars have a higher sulfur content than any of the others, but the pH averages about the same as similarly treated jars of the Eldon soil. The pH is, however, decidedly lower than either of the two western soils as is the percentage of sulfate in the soil.

On the other hand the percentage of sulfur in the crop is distinctly higher in the more acid soil, in spite of its lower sulfate content. Calcium cabonate added to jars of the Eldon soil raised the pH to that of part of the Redmond jars. The percentage of sulfur in crops grown on jars of these two soils with corresponding pH values was practically the same, regardless of the treatment.

With one exception, the sulfate content in the Vale soil is higher with all treatments than any of the other soils receiving similar treatment and yet the

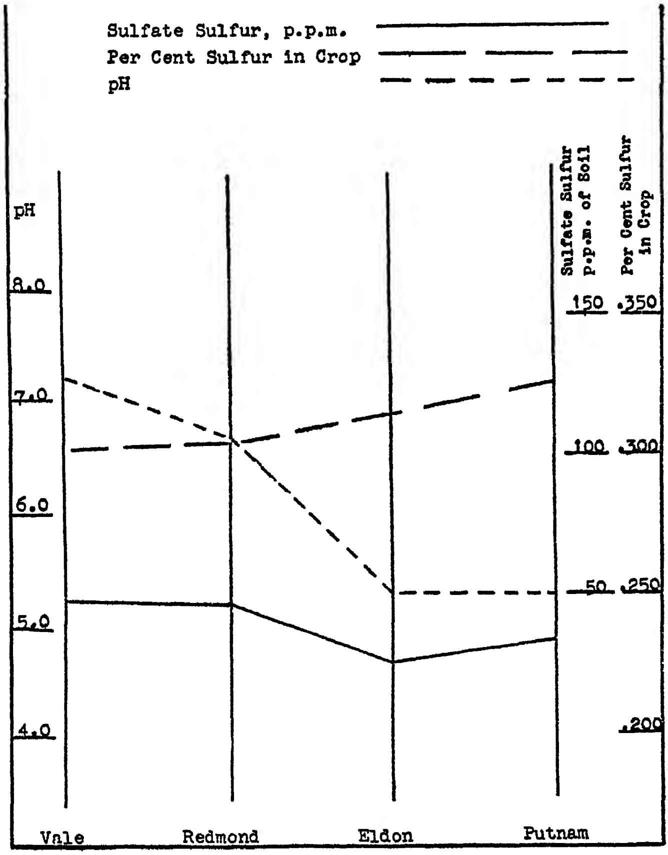

FIG. 1. COMPARISON OF SULFATE SULFUR, PH AND PERCENTAGE OF SULFUR IN THE CROP ON SOILS TREATED WITH 150 POUNDS OF SULFUR PER ACRE

sulfur content of the crops grown on the soil was lower than in the crops grown on the other soils. Although these data are not complete enough to be conclusive, they are of interest in showing additional differences in the effect of sulfate on various soils. It would appear, for instance, that soybeans can secure sulfate more readily from the limited supply in the unlimed jars of the Eldon soil than from the more abundant supply of the western soils, and this might help to explain why this soil, though very low in total sulfur and appar-

ently in sulfute sulfur, gives only a slight response to sulfur treatments when compared to the Redmond soil.

Robbins (11) has found anions to be absorbed more readily from a medium with a reaction on the acid side of the isoelectric point for plant protein. The present work offers some confirmation of this for the sulfate ion. These results are also in accord with the work of Hoagland (6) who has found a greater

TABLE 3

Sulfate sulfur produced in cropped and in fallowed soils

SOIL TREATMENT*	AFTER 38 DAYS		AFTER 77 DAYS		AFTER 120 DAYS	
	Cropped†	Fallow	Cropped†	Fallow	Cropped†	Fallow
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Vale:						
Check	52.0	20.0	72.0	80.0	91.3	85.0
Sulfur 150	49.5	28.3	91.2	95.3	100.7	189.0
Sulfur 500	112.8	67.8	130.3	216.7	225.4	270.0
Redmond:						
Check	26.1	17.1	33.6	41.0	26.2	33.0
Sulfur 150	47.5	53.3	68.2	107.0	82.5	239.0
Sulfur 500	48.8	76.0	80.2	116.0	202.0	266.0
Eldon:						
Check	8.8	4.7	11.0	6.7	13.1	7.3
Sulfur 150	27.6	16.0	52.8	60.6	46.6	59.0
Sulfur 500	74.1	60.0	86.8	180.0	117.9	175.0
$CaCO_3$ 3000	13.5	5.7	....	....	33.0	13.0
Sulfur 150, $CaCO_3$ 3000	34.8	30.3	....	....	89.5	64.0
Putnam:						
Check	10.7	6.0	9.3	8.6	28.2	10.0
Sulfur 150	34.4	17.3	78.7	60.7	87.7	71.0
Sulfur 500	91.2	45.7	110.4	117.0	150.9	150.0
$CaCO_3$ 5500	23.5	9.3	....	....	....	29.0
$CaCO_3$ 5500, Sulfur 150	42.1	24.0	....	....	....	135.0

* Treatments are recorded in pounds per acre.

† The figures in the "Cropped" column represent the sulfur in the crop calculated to p.p.m. of soil, plus the sulfate sulfur in the soil at the time of harvest.

absorption of anions in an acid media, and of Joffe (7) who has found that lowering the pH by the addition of sulfuric acid to soils results in a higher percentage of nitrogen in the alfalfa produced.

SULFATE PRODUCTION IN CROPPED AND FALLOWED SOILS

The figures representing the sulfate production on the cropped soil were secured by determining the total sulfur in the crop produced, calculating this

to parts per million of soil and adding it to the sulfate sulfur found in the soil at the time of harvest. This procedure is based on the general assumption that crops take up all their sulfur in the sulfate form, and also on the particular assumption that practically all the roots and crops were secured. Special care was taken in removing the roots and although a portion of the very fine ones were not secured, the loss in this respect is thought to be very small.

The sulfate sulfur produced in cropped and in un-cropped soils is reported in table 3. It will be noticed that there is a general increase in sulfate on all soils

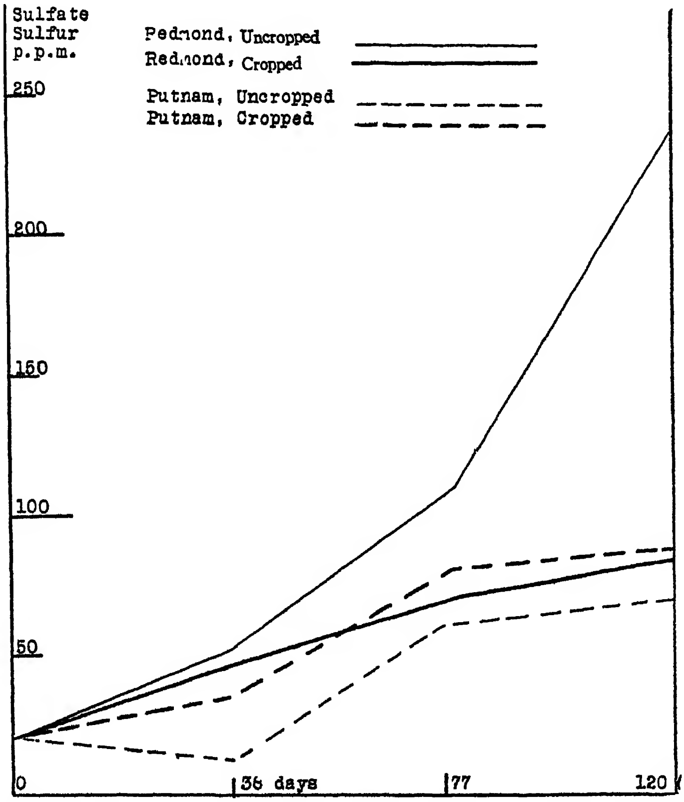

Fig. 2. Sulfate Produced on Cropped and Uncropped Putnam and Redmond Soils Treated with 150 Pounds of Sulfur Per Acre

as a result of sulfur applications and that the sulfate accumulation is greater at the end of the longer period. The sulfate content of the untreated jars changed but little during the course of the experiment in the case of the two Missouri soils, especially in the fallowed jars. Considerable increase with time is apparent in the case of the Vale soil, and to a lesser extent, in the Redmond soil. The effect of the 150 and 500-pound sulfur treatments has been to increase the sulfate for both cropped and fallowed soils at the various stages sampled. Sulfate production in the case of the two acid soils approaches a

maximum at the end of the second period, while an increase throughout the period of study is apparent in the case of the two western soils.

Effect of Crops on Sulfate Production

With all treatments on Putnam silt loam and on untreated jars of the Eldon soil, sulfate production was stimulated by cropping, whereas with all other soils and treatments the reverse was true. The most striking difference is between the Putnam and Redmond soils, the former an acid soil from the humid section which does not require sulfur fertilization and the latter a neutral soil from the semi-arid section on which field applications of sulfur have given marked increases in yield.

Uniform differences in the sulfate produced are found with the 150-pound sulfur treatment (Fig. 2). The difference in favor of the cropped jars is uniform for all three periods in the case of the Putnam soil, whereas with the Redmond soil the curve representing the fallowed jars is higher than that of the cropped soil, the difference becoming constantly greater toward the end of the last period.

In all the soils but the Redmond the crop tended to increase the amount of sulfate produced during the early stages of growth; namely, until the end of the first period. After this time the fallowed soils were more efficient in sulfofication, except as has been noted with the Putnam soil and with the untreated jars of the Eldon silt loam.

It is interesting to compare these results with those secured by other investigators with the effect of crop growth on nitrate production. Lyon, Bizzell and Wilson (9) found that maize did not depress nitrate accumulation during the early growth, but did so later. Wheat, unlike maize, showed a depressing influence at the end of the first period and continued to exert this depression throughout the entire period of growth. These authors explain this phenomenon as being due to the liberation by the plant roots of non-nitrogenous organic matter which is thought to favor the development of nitrate-consuming organisms in the soil with the consequent transformation of nitrate into other nitrogenous substances. Lyon and his colleagues worked with a heavy silty clay loam soil and believe that with a more highly aerated soil the depression of nitrate accumulation might not occur, since the organic acids liberated would be more completely oxidized. Texture has not had this effect in the present study. The depressing effect of the crop on sulfate formation has been most pronounced on a loose sandy loam soil, whereas on the heaviest and least aerated of the soils studied the crop stimulated sulfate production.

Greaves (4) quotes McBeth and Smith to the effect that plots continuously cropped to alfalfa, potatoes, oats, and corn, all show a higher nitrifying power than do corresponding fallow plots, with the greatest stimulation occurring from alfalfa. It would appear that probably the stimulating or depressing

effect of the crop on nitrification may vary with different soils, as has been shown for sulfofication in the present study.

THE RECUPERATIVE POWER OF SOILS FOR SULFATE

After depletion by crop

Some work was done to test the power of the soils studied to build up in total sulfate after the supply has been depleted. After removing the roots and sampling the soils from the cropped jars at the end of the second period, the soil was returned to the jars and was kept up in moisture content for 12 weeks.

TABLE 4

Recuperative power soils for sulfate (after depletion by cropping)

SOIL AND TREATMENT*	SULFATE SULFUR AT TIME OF HARVEST	SULFATE SULFUR LOSS OR GAIN	
		7 weeks after harvest	12 weeks after harvest
	p.p.m.	*p.p.m.*	*p.p.m.*
Vale:			
Check	64.0	+28.0	+26.0
Sulfur 150	79.0	+28.0	+29.0
Sulfur 500	119.0	+11.0	+119.0
Redmond:			
Check	25.0	−6.0	−3.0
Sulfur 150	60.0	−28.0	−13.0
Sulfur 500	61.0	+5.2	+77.0
Eldon:			
Check	3.7	−0.7	+5.3
Sulfur 150	45 0	−8.0	−9.0
Sulfur 500	72.0	+2.0	+48.0
Putnam:			
Check	2 3	+1.7	+13.7
Sulfur 150	68.0	−28.0	−23.0
Sulfur 500	96.0	+20.0	+48.0

* Treatments are recorded in pounds per acre.

At the end of 7 weeks and again after 12 weeks from the date of harvest, samples were taken and the water-soluble sulfate was determined. The results are recorded in table 4. It will be noted that although the data secured are not uniform and probably do not represent enough trials to warrant definite assumptions, some rather interesting conditions are indicated.

The general difference, between the soils that have shown a need for sulfur and those which do not profit from its use is very well defined, particularly in case of the untreated soils. The Vale soil has built up quickly in sulfate after the crop was removed and this was true to a lesser extent with Putnam silt

loam. In the Redmond and the Eldon silt loam, however, the supply of sulfate is increased very slowly after a depletion by cropping. This difference in the recuperative power for sulfate accumulation may explain in part the variation in response to sulfur fertilizers, especially where permanent crops such as alfalfa are produced.

Percolation tests

In order to test this point further, percolation tubes containing 1500 and 1600 gm. of the Putnam and Redmond soils, respectively, were set up and leached with distilled water until the percolate failed to give a qualitative test for sulfate. Aliquots of the percolate were taken, and the sulfate was determined and calculated as parts per million of sulfate sulfur on the basis of the water-free weight of the soil. The tubes were kept in the laboratory and maintained at optimum moisture with distilled water for a period of 14 weeks after which they were again leached and the percolate analyzed in the same

TABLE 5

Recuperative power of soils for sulfate (percolation trials)

SOIL	SULFATE SULFUR IN PERCOLATE	
	At start	After 14 weeks
	p.p.m.	*p.p.m.*
Redmond medium sand	45 31	15.87
Duplicate	43 06	15.62
Average	44 18	15.74
Putnam silt loam	32 68	26.70
Duplicate	34 02	29.15
Average	33 35	27 92

way. The results of duplicate percolation tubes from each of the two soils are recorded in table 5.

It will be noted that the Redmond soil, which had the highest sulfate content at the time of the first leaching, built up its sulfate supply only 15.7 p.p.m. at the end of 14 weeks, whereas the Putnam soil, which had a lower total sulfate content in the first percolate, increased to approximately 28 p.p.m. These figures are in accord with the results secured by comparing the increase after cropping. The difference in favor of the Putnam soil was really greater than is apparent in this table, as it was impossible, because of the way the soil had run together by the end of the second period, to leach out all the sulfate.

DISCUSSION

Of the soils studied, Redmond medium sand not only needs a higher percentage of sulfate for proper crop growth, but its ability to produce sulfate has been reduced by cropping, and the power of this soil to build up in sulfate,

after a depletion by cropping, appears to be insufficient to supply the needs of the crop. The Vale soil also required a high sulfate content for the use of crops, but the sulfofying capacity was so great and the total sulfur content so high that an abundant supply of sulfate was maintained. The Eldon soil apparently did not require a large amount of sulfate for crop production. Its need for sulfur treatments seemed to be due largely to the low percentage of total sulfur and to the fact that it did not build up in sulfate quickly after a depletion by cropping. The Putnam soil not only made an efficient use of its sulfate but the rate of sulfofication was increased so markedly by cropping that the small amount of sulfate required was maintained throughout the growth period. This soil also quickly built up a supply of sulfate after the crop was removed.

The points which have just been discussed are not brought out in a study of the uncropped soil. It would appear that these differences in the sulfur relations of soils and crops are of importance in explaining the fact that a need for sulfur fertilization has not been apparent on many middle western soils with as low a total sulfur and sulfate content as some semi-arid soils on which yields have been greatly increased by field applications of sulfur fertilizer.

CONCLUSIONS

Under the conditions of these tests, the crop grown on the western soil that has given returns for sulfur, has retarded the formation of sulfate. Crop growth on the humid soils has increased the production of sulfate and thus probably has helped to supply the crop with this material.

Under conditions of higher H-ion concentration as was the case with the humid soils it seems probable that crops may be able to extract sulfur more readily from the soil and therefore not require so great a continuous supply as when grown on semi-arid soils. Furthermore, humid soils may recuperate more readily in their sulfate content, and hence have a sufficient supply of sulfate for the crop at practically all times. On the other hand, it would be more difficult for some of the semi-arid soils, such as the one from Redmond used in this work, to regain enough sulfate for satisfactory growth, after it once had been depleted. This condition most likely would be found in field practice where perennial sod crops have occupied the land for considerable time, and may offer some explanation for the marked returns that have been obtained from the use of sulfur on certain alfalfa lands in the semi-arid regions of the West.

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THE EFFECT OF SULFUR ON THE MICROFLORA OF THE SOIL

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Sulfur is a vital part of the protein molecule, hence it is required by all plants and animals. All bacteria require it as a structural element and some use it as a source of energy. The quantity present in the soil of our Greenville experimental farm is low, 0.0068 per cent total sulfur (7) in the first foot. This being the case, the question naturally arises: What effect will the addition of sulfur to such a soil have upon its microflora? The data presented in this paper are an attempt to answer this question.

The Greenville soil is an ideal medium in which to make such a study, as it has an abundance of all the essential elements except sulfur and nitrogen, and it has a most interesting microflora (6, 7).

Boullanger (3) studied the action of sulfur on sterilized and unsterilized soil and found the increase in crop yield, due to the sulfur, was much greater on unsterilized soil. This action he considered to be due to the oxidation of sulfur by bacteria. This is confirmed by Demolon (5) with garden soil. The sulfofying power of soils varies with the composition, texture, moisture, and biological conditions (4). Lipman and co-workers (12) studied the oxidation of sulfur and its relations to insoluble plant-food. Sulfur is oxidized by certain bacteria to sulfuric acid as follows (10): $2S + 3O_2 + 2H_2O = 2H_2SO_4$. The acid reacts with insoluble phosphates rendering them soluble: $Ca_3(PO_4)_2 + H_2SO_4 + 2H_2O = Ca_2H_2(PO_4)_2 + CaSO_4 \cdot 2H_2O$.

$$Ca_2H_2(PO_4)_2 + H_2SO_4 = CaH_4(PO_4)_2 + CaSO_4$$

Many tests have been made to determine the effect of added sulfur on crop production. Reimer and Tartar (16) increased the yield of alfalfa and clover from 35 to 1000 per cent by the addition of sulfur to certain Oregon soils. The addition of sulfur to the soil increased the nitrogen content of plants and also the nodule production (13, 17). Rudolfs (17) using soybeans found that small amounts of sulfur increased the growth of the root systems. He also found that sulfur increased bacterial numbers during the first 6 weeks, when the sulfur application did not exceed 1500 pounds per acre. Greater quantities caused a decrease in numbers. This was confirmed by O'Gara (14).

[1] The author is greatly indebted to Dr. J. E. Greaves for his keen interest in this work and for his advice and suggestions, and to Dudley Greaves for making the graphs.

Small amounts of sulfur increase ammonification (1, 15), whereas nitrification is retarded (1, 15). Sulfur oxidation is greater in soils low in organic matter and in mineral nutrients (17). One experiment shows that sulfur oxidation was greatest in soil which had no fertilizer for 33 years.

The addition of sulfur to black alkali soil in the presence of sulfur-oxidizing bacteria transforms the black alkali into white alkali (8, 14, 18, 21), thus indicating the possibility of its use in reclamation of alkali land.

The most important sulfur bacteria found in soils to which sulfur has been added are *Thiobacillus thioparus*, *Thiobacillus dentrificans* and *Thiobacillus thiooxidans* (19). The first two organisms develop under neutral or slightly alkaline conditions whereas the latter develops in extremely acid media reactions. Starkey (19) states that *Thiobacillus thiooxidans* not only tolerates but produces higher concentrations of acid than any other living organism.

In this work a laboratory study was made of the influence of varying amounts of sulfur on the soil microflora as measured by numbers, ammonification, nitrification, azofication, and the rate at which the sulfur is oxidized to sulfates.

Three soils were used, two of which were taken from the Greenville experimental farm located 2 miles north of the Utah Agricultural College. Soil A was taken from a plot which was very low in organic matter (this plot had received no manure for 12 years). Soil B was taken from a nearby plot which was very high in organic matter (40 tons of manure per acre had been applied yearly for 12 years). These soils are very high in calcium and magnesium carbonates (9) and exceptionally rich in potassium and phosphorus, but they are low in nitrogen. They are composed primarily of coarse and medium silt and fine sand. Soil C was taken from a farm in River Heights, 2 miles southwest of the college. This soil has a medium organic content and consists principally of coarse silt and medium sand. It is high in calcium and magnesium carbonates with ample amounts of phosphorus and potassium present, but low in nitrogen.

The three soils used were air-dried in the dark and were ground to pass a 40-mesh sieve, after which 100-gram portions were weighed into clean covered tumblers, to each of which were added quantities of sulfur varying from 100 to 1000 pounds per acre. One acre-foot of soil was assumed to weigh 3,600,000 pounds. The ammonifiers and nitrifiers, received in addition to the sulfur, 2 per cent dried blood containing 0.0272 per cent nitrogen (6). The nitrogen fixers received the same sulfur application and 2 per cent mannite. Each sample was thoroughly mixed and the water content made up to 60 per cent of the water-holding capacity. It was kept close to this amount by weekly weighings and the loss was made up with distilled water.

Four sets of each soil were prepared in the foregoing manner and incubated at 28°. After 4 days one set of each soil was analyzed for ammonia by the standard magnesium-oxide method (2). The bacterial counts were made at monthly intervals by the plate method using nutrient agar with a + 0.1 per cent reaction.

To determine sulfur oxidation 15 samples of each soil were prepared: to 9 of each soil was added 21.6 mgm. of sulfur; the remaining 6 received no sulfur and served as controls. The samples were thoroughly mixed and the moisture content made up to 60 per cent of the water-holding capacity, which was kept close to this percentage by weekly additions of distilled water. The three soils were incubated at 28° and the soluble sulfate was determined in three

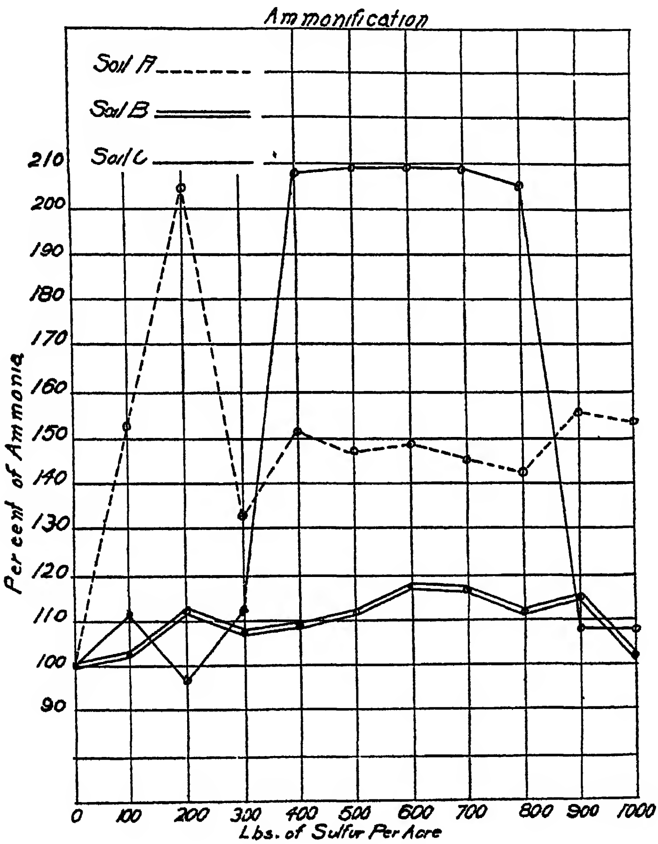

Fig. 1. Percentage of Ammonia Produced in Soils Treated with Varying Amounts of Sulfur

The untreated soil was considered as 100 per cent

sulfur-treated samples and two untreated samples of each soil at intervals of 10 days. The sulfates were determined by agitating the soil with distilled water in a shaker for 5 hours, filtering clear, and precipitating as barium sulfate.

The results obtained for ammonification are given in figure 1. It is very evident that sulfur greatly stimulates ammonification in all three soils. Soil A showed greatest stimulation at the lower concentrations of sulfur. Sulfur

increased ammonification 100 per cent when small concentrations were used and 50 per cent with large concentrations.

The stimulation was not so great in soil B as in soils A and C. This is probably due to the large amounts of available plant-food already present in the soil, which has been carried there by the heavy applications of manure. Ammonification was increased most in soil C; although sulfur appeared to be

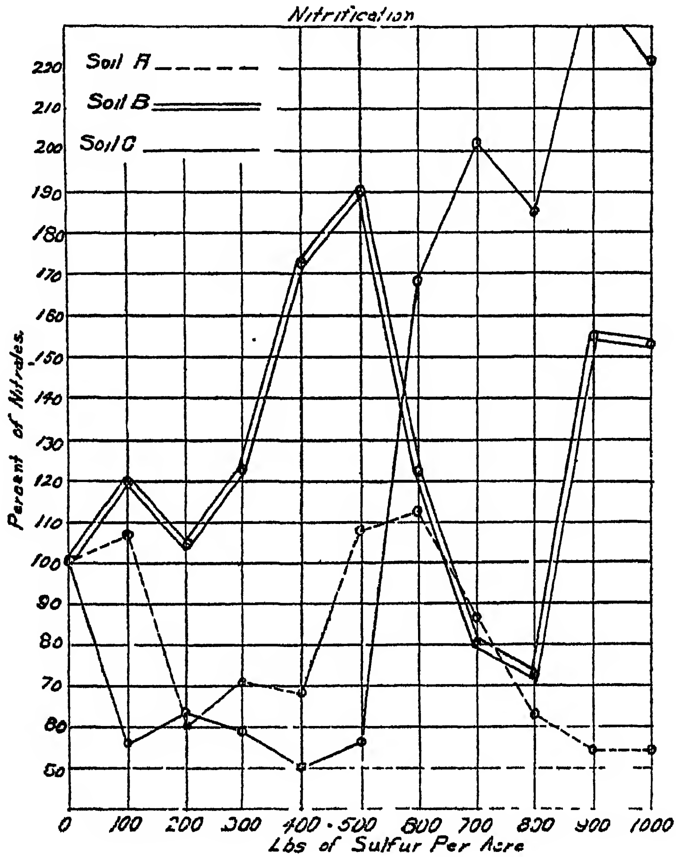

FIG. 2. PERCENTAGE OF NITRATES PRODUCED IN SOILS TREATED WITH VARYING AMOUNTS OF SULFUR

The untreated soil was considered as 100 per cent

slightly toxic in the second concentration, recovery was very marked in higher concentrations. When 400 pounds per acre of sulfur was applied to the soil, ammonification was increased 110 per cent. The probable cause of the great stimulation may be due to two factors:

(a) There may be a very small amount of available food present in the soil; consequently, the food made available by the oxidation of the sulfur would be quickly utilized, thus increasing the number of bacteria as well as their physiological efficiency. (b) The soil is in ideal

condition for the rapid oxidation of the sulfur, as it is loose and porous, thus admitting large amounts of oxygen and carbon dioxide which are necessary for the optimum activity of the sulfur organisms.

The nitrifying organisms responded to sulfur applications very differently from the ammonifying organisms. The sulfur was very toxic in soil A, the highest concentrations of sulfur appearing to be slightly more toxic than the lower concentrations. Nitrification was greatly stimulated in soil B by sulfur in all the concentrations with the exception of the seventh and eighth. At these two the sulfur became toxic. Although the sulfur was very toxic at all the lower concentrations, in soil C, a great stimulation occurred in the higher concentrations. In explanation of the broken line in soil C (fig. 2) it may be

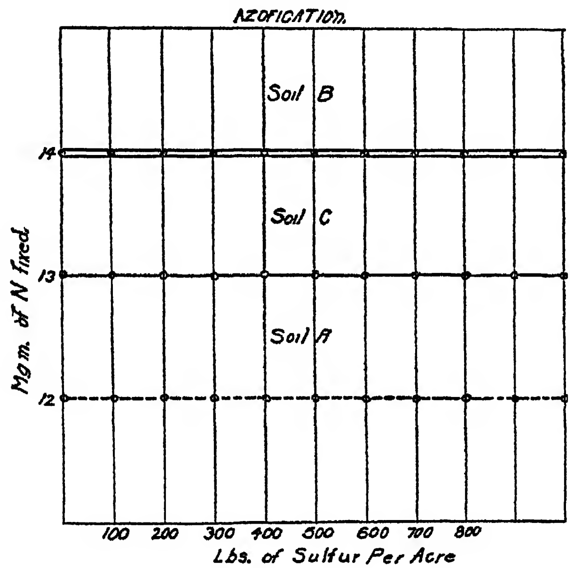

FIG. 3. MILLIGRAMS OF NITROGEN FIXED IN SOILS TREATED WITH VARYING AMOUNTS OF SULFUR

stated that an erratic result was obtained in the ninth concentration which threw the percentage of nitrates formed to 300 per cent above the untreated soil. It is very evident that the organic matter is playing a great part in the stimulation of nitrate production. The only difference in soils A and B is that soil B contains large amounts of organic matter, whereas soil A contains none.

The sulfur was without effect on azofication during the short time the soil was under observation, as may be seen from figure 3.

The number of colonies developing on nutrient agar from sulfur-treated and non-sulfur-treated soil is shown in figure 4.

There is a general decrease in the number of bacteria over the period the counts were made in the treated and in the untreated soils. Soils A and C

show a very slight increase in bacterial numbers when 5.4 mgm. of sulfur was present for each 100 gm. of soil, in comparison with the untreated soil. An increase in bacterial numbers was noted in soil B at the higher concentrations of sulfur.

If the bacterial numbers had been determined at weekly intervals during the time of incubation, it is very probable that a considerable increase due to the sulfur would have been noted.

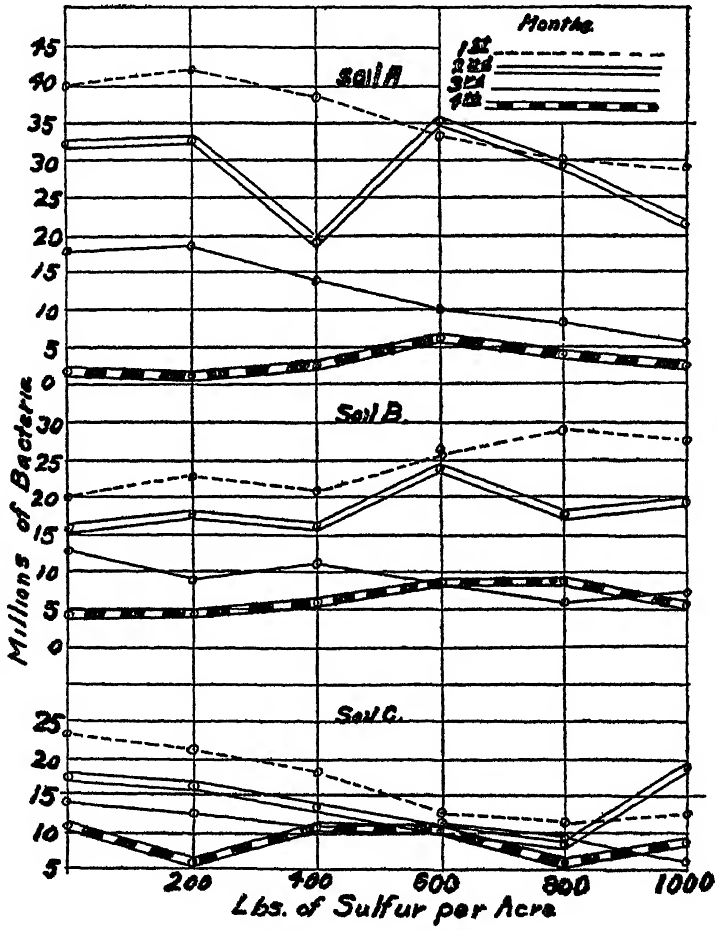

FIG. 4. MILLIONS OF BACTERIA IN SOILS TREATED WITH VARYING AMOUNTS OF SULFUR

The speed with which the sulfur is oxidized to sulfates is governed largely by the aeration of the soil. The physical composition of soil C makes conditions ideal for the free circulation of air. This is the chief cause of the very rapid oxidation of sulfur in this soil. In comparing the sulfur-oxidizing power of soils A and B, which vary only in organic content, a considerable difference

is noted in the amount of sulfur oxidized. Soil A, which was very low in organic matter, oxidized 36 per cent of the added sulfur in 30 days, whereas soil B, which contained large amounts of organic matter, oxidized 45 per cent of the added sulfur in the same period of time.

The addition of sulfur to soil increased the ammonifying power of the soil from 50 to over 100 per cent depending upon the soil and upon the amount of sulfur applied.

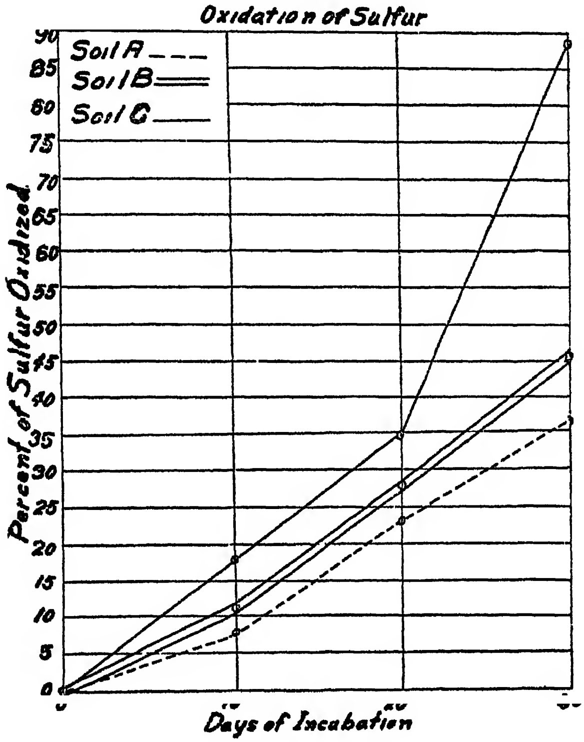

FIG. 5. PERCENTAGE OF SULFUR OXIDIZED IN SOILS TREATED WITH SULFUR

The untreated soil was considered as 100 per cent

Nitrification was increased over 100 per cent in some instances, the extent depending upon the soil and upon the quantity of sulfur added.

Sulfur was without effect on the azofication of the soil during the short period it was under observation.

The bacterial counts decreased as the incubation period increased. Relative to the untreated soil, the bacterial numbers increased as the amount of sulfur increased, in the soil high in organic matter; whereas the bacterial number of soils low in organic matter decreased as the sulfur increased.

From 36 to 89 per cent of the sulfur was oxidized to sulfates in 30 days, depending on the soil and its porosity.

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THE FORM OF LEGUME NITROGEN ASSIMILATED BY NON-LEGUMES WHEN GROWN IN ASSOCIATION[1]

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That non-legumes, when grown in association with inoculated legumes under favorable conditions, profit by the association is a well established fact. It is also generally conceded that this beneficial influence upon the non-legume is due to some nitrogenous substance placed at its disposal by the inoculated legume. Just what the exact nature of this nitrogenous substance is, however, is not known. The work reported in this paper was planned to throw some light upon this question.

EXPERIMENTAL

Two soils and nitrogen-free sand were used in these experiments. One of the soils was glacial in origin, occurring in the Wisconsin drift soil area, and the other was a residual soil, arising from coastal plain deposits, and occurring in the coastal plain soil area. One, classified by the Bureau of Soils as Carrington loam, was used for series I, and the other, classified as Lufkin fine sandy loam, was used for series II and III. These soils vary widely in their general characteristics and crop-producing power. The former is dark brown to black in color, well supplied with humus and nitrogen, and is considered to be a very productive soil; the latter is grayish to grayish-brown in color, low in humus and nitrogen, and is considered to be a very unproductive soil. Analysis showed 0.3408 per cent nitrogen in the Carrington loam. Analysis of the Lufkin fine sandy loam showed 0.0788 per cent nitrogen, 0.037 per cent total phosphoric acid, 1.16 per cent potash, 0.32 per cent acid-soluble lime, 0.28 per cent acid-soluble magnesia, 0.08 per cent sulfur trioxide, and by the Truog method, a lime requirement of 1 ton.

Soybeans and wheat, grown alone and in association, were the plants used. Each series except the nitrogen-free sand series consisted of 14 pots. For series I, II, and III, 2-, 3-, and 1-gallon pots, respectively, were used. The 2-gallon pots were used during the early part of the experiment but 3-gallon

[1] Part of the thesis submitted to the Faculty of the Iowa State College in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

[2] The writer wishes to express his appreciation to Dr. P. E. Brown for suggestions concerning the work and the manuscript and to Dr. L. W. Erdman for suggestions concerning the preparation of the manuscript.

pots were used later for the unsterilized, and 1-gallon for the sterilized soil. The soil was sterilized by autoclaving at 15 pounds for 1 hour. All inoculated soils received cultures containing the proper bacteria to bring about inoculation.

Large samples of the two soils were secured from the field, sieved, thoroughly mixed, and placed directly in the pots and weighed. The 3-gallon pots were filled with 15 kilos, the 2-gallon with 10 kilos and the 1-gallon with 5 kilos of air-dried soil. Soybeans and wheat were seeded in the pots of series I, II, and III, as shown in table 1.

The 2- and 3-gallon pots were allowed two and three times the number of plants, respectively, as in table 1.

TABLE 1

System of numbering pots and rates of seeding wheat and soybeans in series III

POT NUMBER	TREATMENT
	First harvest
1	Wheat, 6 plants, grown alone
2	Soybeans, 4 plants, grown alone
3	Wheat, 3 plants, grown with soybeans
4	Soybeans, 2 plants, grown with wheat
CK	Check, uncropped
	Second harvest
5	Wheat, 6 plants, grown alone
6	Soybeans, 4 plants, grown alone
7	Wheat, 3 plants, grown with soybeans
8	Soybeans, 2 plants, grown with wheat
CK	Check, uncropped
Orig.	Original soil

Pure cultures of the soybean organism were added to each pot and the moisture content was brought up to the optimum by adding water to weight. The moisture content was kept up during the continuance of the experiment by weighing the pots twice each week and adding distilled water to weight. The 1-gallon pots were numbered and planted as shown in table 1.

In each test the crops were harvested from duplicate pots at two stages of growth. The first harvest was made from pots 1 to 6 inclusive when the first blooms appeared on the soybeans. The second harvest was made from pots 7 to 12 inclusive when the first pods were about half mature. The soil in the check pots was sampled at both harvests. The plants were cut near the surface of the soil, and the roots carefully removed from the soil. The tops, roots, and nodules were dried and weighed. They were then finely ground and the soil, tops, roots, and nodules analysed for ammonia, nitrites, nitrates, amino acids, and total nitrogen. Duplicate determinations were

made on each sample, except in cases where there was an insufficient amount of the sample, and the results were required to agree very accurately. Repeats as well as blank determinations on reagents were run in all necessary cases. The results given in the tables are the averages of duplicate determinations on duplicate pots.

A coarse white sand was used in the nitrogen-free sand series. Eight 1-gallon pots were filled with 5 kilos of sand after mixing in 10 gm. of pure calcium carbonate. The plants in each pot received the following fertilizer treatment each week:

10 cc. each of:	25 gm. $CaH_4(PO_4)_2$	per 2,500 cc. water
	20 gm. $MgSO_4$	per 2,500 cc. water
	50 gm. K_2SO_4	per 2,500 cc. water
1 cc. of:	0.1 gm. $FeCl_3$	per 250 cc. water

These amounts were diluted with water and added to the plants.

Each pot was planted to 6 soybeans, the beans in the last 6 pots being inoculated with a pure culture solution before planting.

The roots, and the sand immediately around the roots, in pots 1 and 2, which were not inoculated, were analyzed for ammonia, nitrites, nitrates, and amino acid nitrogen. The same was done for pots 3 and 4 just at the time when the plants recovered from the period of "nitrogen hunger." The plants in the other 4 pots were harvested at the same stages as those of the soil and handled in a similar manner.

METHODS

Total nitrogen. For all total nitrogen determinations the copper sulfate method was used. A 10-gm. sample of soil, a 0.5- to 1-gm. sample of tops and roots, and a 0.1–0.5-gm. sample of nodules were used. The samples were carefully weighed in duplicates, where the amount of material was sufficient, and transferred to an 800-cc. Kjeldahl flask. About 10 gm. of a mixture of potassium sulfate and copper sulfate—100 gm. of potassium sulfate to 10 gm. of copper sulfate—was added and then from 25 to 30 cc. of concentrated sulfuric acid. The remainder of the process was the same as with any total nitrogen determination by the distillation method. For titrating, 0.05*N* sulfuric acid and 0.025*N* sodium hydroxide were used. Sodium alizarine sulfonate indicator was used throughout.

Ammonia. The colorimetric method for determining ammonia, as outlined in Bureau of Soils Bulletin 31, was used for determining the ammonia in both soil and plants.

Nitrites. The colorimetric method for determining nitrites, as outlined in Bureau of Soils Bulletin 31, was used for determining the nitrites in both soil and plants.

Nitrates. Davis' modification of the phenoldisulfonic acid method for determining nitrates in soils[3] was used for both plants and soils.

Amino acids. For the determination of amino acid nitrogen the Van Slyke method[4] was used.

Soil solutions. The soil was first air-dried, finely ground, and thoroughly mixed. One hundred-gram portions were carefully weighed into 800-cc. bottles. About 10 gm. of carbon black, special brand G. Elf., and 200 cc. of distilled water were added. The contents were

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[3] Outlined in Jour. Indus. and Engin. Chem., v. 9, p. 290–295.

[4] Outlined in Jour. Biol. Chem., v. 9, p. 185–191.

shaken for 30 minutes and filtered through double folded filter paper, the first 50-cc. portions of the filtrate being discarded or poured back into the bottle for refiltering. This usually gave a clear solution.

Plant extract solution. The tops, roots, and nodules, were first dried in an electric oven and finely ground in a small grinding machine or mill. Samples were weighed, varying in size from a fraction of a gram to 10 gm., depending upon the amount of substance available, and transferred to 800-cc. shaker bottles, 500 cc. of distilled water and about 10 gm. of carbon black, special brand G. Elf., being added. The contents were shaken vigorously for about three minutes and allowed to stand for about twenty minutes with occasional shaking. The filtering was done as in the case of the aforementioned soil. The solution was then ready for use.

Series I

In this series soybeans and wheat were grown alone, and in association, on Carrington loam. The weights of tops, roots, nodules, and plants secured at the first and second harvests are given for each pot in table 2.

TABLE 2

Dry weight of plants grown in Carrington loam

POT NUMBER	TREATMENT	TOPS	ROOTS	NODULES	PLANTS
		gm.	*gm.*	*gm.*	*gm.*
	First harvest				
1	Wheat........................	12.84	12.59	....	25.88
2	Soybeans.....................	22.36	12.48	2.25	37.09
3	Wheat with soybeans...........	6.72	5.61	....	9.33
4	Soybeans with wheat...........	10.65	5.42	*	16.08
	Second harvest				
5	Wheat........................	33.00	27.00	....	60.00
6	Soybeans.....................	78.50	14.25	4.75	97.50
7	Wheat with soybeans...........	10.00	6.50	....	16.50
8	Soybeans with wheat...........	49.50	4.50	2.90	56.90

* Weight of nodules lost.

The yields given in table 2 show that the combined weight of tops and plants of soybeans and wheat grown in association was greater than wheat, but less than soybeans, grown alone. This was to be expected, since it is generally conceded that non-legumes derive considerable benefit from inoculated legumes when grown in association under favorable conditions. In the case of the roots the combined weight of soybeans and wheat grown in association was less than of soybeans and wheat grown alone.

The data given in table 3 show the amount of ammonia in the soil, tops, roots, and nodules at the first and second harvests.

An examination of this table shows that ammonia was present more or less abundantly in the soil, tops, roots, and nodules at both harvests. The soil cropped to the soybean-wheat mixture contained more ammonia than that

cropped to soybeans but less than that cropped to wheat alone at the first harvest. The soil of the soybean-wheat mixture contained an average of 0.0252 p.p.m. as compared with 0.0263 for the soybeans and 0.0801 for wheat alone at the second harvest.

The wheat tops grown in association with soybeans contained an average of 71.16 and 20.04 p.p.m. of ammonia as against 43.75 and 10.35 p.p.m. for wheat tops grown alone at the first and second harvests, respectively. The amounts of ammonia for the corresponding soybeans were 27.77 and 11.84 p.p.m. for the soybeans grown in association with wheat as against 32.88 and 14.86 p.p.m. for soybeans grown alone at the first and second harvests, respectively.

TABLE 3

Ammonia in soil, tops, roots, and nodules obtained in series I

POT NUMBER	TREATMENT	SOIL	TOPS	ROOTS	NODULES
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
	First harvest				
1	Wheat	0.0413	43.75	15.70	......
2	Soybeans	0.0323	32.88	10.18	138.85
3	Wheat with soybeans	0.0357	71.16	40.47	......
4	Soybeans with wheat	0.0357	27.77	10.67	92.07
CK	Check	0.0728	.....	.....	......
	Second harvest				
5	Wheat	0.0801	10.35	4.74	......
6	Soybeans	0.0263	14.86	6.49	47.96
7	Wheat with soybeans	0.0252	20.04	10.55	......
8	Soybeans with wheat	0.0252	11.84	17.22	56.21
CK	Check	0.0331	.....	.....	......
Orig.	Original soil	0.1492	.....	.....	......

The difference between the ammonia content of the roots of the wheat plants grown in association with soybeans and those grown alone, was as pronounced as that of the tops. The roots of the wheat plants grown in association with soybeans contained 40.47 and 10.55 p.p.m. of ammonia as compared with 15.70 and 4.74 p.p.m. for wheat grown alone at the first and second harvests, respectively. The amounts of ammonia for the roots of the corresponding soybeans were 10.67 and 17.22 p.p.m. for soybeans grown in association with wheat as compared with 10.18 and 6.49 p.p.m. for soybeans grown at the first and second harvests, respectively. The tops and roots of wheat plants grown in association with soybeans contained more ammonia at both harvests than those of corresponding wheat plants grown alone.

The nodules showed the presence of an abundance of ammonia in all cases. The nodules of the first harvest had a higher ammonia content than those of

the second. The ammonia content of the nodules from the soybean plants grown alone was considerably higher than that of soybean plants grown in association with wheat for the first harvest, but for the second those from the soybean plants grown in association with wheat averaged a little higher than those from the soybean plants grown alone.

In table 4 are contained the amounts of nitrites in the soil, tops, roots, and nodules for each pot at both harvests. There were no striking differences in the nitrite content of the soil of the different pots at the first harvest. The soil in which the soybeans and wheat were grown in association contained 0.0104 p.p.m. as against 0.0125 and 0.0080 p.p.m. for soybeans and wheat grown alone, respectively, for the second harvest.

TABLE 4

Nitrites in soil, tops, roots, and nodules obtained in series I

POT NUMBER	TREATMENT	SOIL	TOPS	ROOTS	NODULES
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
	First harvest				
1	Wheat	0.0010	5.8785	0.0660	.....
2	Soybeans	0.0011	0.2920	0.1527	20.49
3	Wheat with soybeans	0.0011	1.1040	0.3220	.....
4	Soybeans with wheat	0.0011	0.1980	0.0794	20.49
CK	Check	0.0014	......	......	.....
	Second harvest				
5	Wheat	0.0080	0.0046	0.3185	.....
6	Soybeans	0.0125	0.0075	0.4524	9.04
7	Wheat with soybeans	0.0104	0.0092	0.3518	.....
8	Soybeans with wheat	0.0104	0.0056	5.8905	3.85
CK	Check	0.0146	......	......	.....
Orig.	Original soil	0.0016	......	......	.....

The wheat tops grown in association with soybeans contained an average of 1.104 and 0.0092 p.p.m. as compared with 5.87 and 0.0046 p.p.m. of nitrites for wheat tops grown alone at the first and second harvests, respectively. The corresponding soybean plants contained 0.198 and 0.0056 p.p.m. of nitrites in tops when grown in association with wheat, and 0.292 and 0.0075 p.p.m. of nitrites for soybeans grown alone at the first and second harvests, respectively. The average nitrite content of wheat roots grown in association with soybeans was 0.322 and 0.3518 p.p.m. as compared with 0.066 and 0.3185 p.p.m. for the roots of wheat grown alone for the first and second harvests, respectively. The nitrite content of the roots of the corresponding soybeans was 0.0794 and 5.89 p.p.m. for soybeans in association with wheat, and 0.1527 and 0.4524 p.p.m. for soybeans grown alone at the first and second harvests, respectively.

The soybean nodules contained nitrites in all cases, the amount being much lower at the second harvest than at the first, and considerably less for the nodules grown in association with wheat than those grown alone at the second harvest. The difference in the nitrite content of the nodules of the soybean plants grown in association with wheat, and alone, was only very slight for the first harvest.

Table 5 contains the amounts of nitrates in the soil, tops, roots, and nodules for each pot at both harvests. An examination of this table reveals the fact that the nitrate content of the soil in the soybean-wheat pots was slightly greater than that of the wheat and less than that of the soybean pots at the time of both harvests. The difference was more pronounced at the second than at the first harvest.

TABLE 5

Nitrates in soils, tops, roots, and nodules obtained in series I

POT NUMBER	TREATMENT	SOIL	TOPS	ROOTS	NODULES
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
	First harvest				
1	Wheat	0.0027	54.85	10.02	.....
2	Soybeans	0.0039	4.79	22.23	None
3	Wheat with soybeans	0.0035	62.95	35.89	.....
4	Soybeans with wheat	0.0035	6.38	19.01	None
CK	Check	0.0453	.....	.....	.....
	Second harvest				
5	Wheat	0.0875	2.58	1.02	.....
6	Soybeans	0.1310	2.78	3.38	None
7	Wheat with soybeans	0.1251	7.14	1.91	.....
8	Soybeans with wheat	0.1251	2.14	2.64	None
CK	Check	1.3333	.....	.....	.....
Orig.	Original soil	0.0400	.....	.....	.....

The average nitrate content of the wheat tops grown in association with soybeans was 62.95 and 7.14 p.p.m. as compared with 54.85 and 2.58 p.p.m. for wheat grown alone at the first and second harvests, respectively. The average nitrate content of the tops for the corresponding soybean pots was 6.38 and 2.14 p.p.m. where soybeans were grown with wheat, and 4.79 and 2.78 p.p.m. where soybeans were grown alone at the first and second harvests, respectively.

The nitrate content of the roots of wheat grown with soybeans was greater at both harvests than that of wheat roots grown alone. The reverse was true for the soybeans. The roots of the soybeans grown in association with wheat contained 19.01 and 2.64 p.p.m. of nitrates as compared with 22.23 and 3.38 p.p.m. at the first and second harvests, respectively. The nodules were free from nitrates in all cases.

The data presented in table 6 show the amounts of amino acids in the soil, tops, roots, and nodules obtained in series I. An examination of this table reveals the absence of amino acids in the soil in all samples. The wheat tops contained a higher amino acid content than the soybean, except in case of the wheat tops of the soybean-wheat mixture at the second harvest when the soybean tops had a slightly larger amount of amino acid than the wheat. This difference was very slight, however. The amino acid content of the wheat tops in the soybean-wheat mixture was slightly greater than that of the wheat alone for the first harvest and less for the second. The soybean tops of the soybean-wheat mixture had a higher amino acid content than those grown alone.

TABLE 6

Amino acid nitrogen in soil, tops, roots, and nodules obtained in series I

POT NUMBER	TREATMENT	SOIL	TOPS	ROOTS	NODULES
		cc. N	*cc. N*	*cc. N*	*cc. N*
	First harvest				
1	Wheat	None	14.61	2.76	......
2	Soybeans	None	8.00	3.90	121.36
3	Wheat with soybeans	None	15.11	2.11	......
4	Soybeans with wheat	None	8.09	1.69	85.00
CK	Check	None	.....	....	......
	Second harvest				
5	Wheat	None	7.05	0.09	......
6	Soybeans	None	2.66	0.00	17.95
7	Wheat with soybeans	None	4.75	0.50	......
8	Soybeans with wheat	None	4.66	1.97	13.10
CK	Check	.....	.....	....	......
Orig.	Original soil	.....	.....	....	......

There was nothing significant about the amino acid content of the roots other than that it was much lower for the roots than for the tops, and that the roots of the second harvest contained considerably less amino acid than those of the first.

Amino acid was present in the nodules in all cases. The amount was greater with the first harvest than with the second and also greater for the soybeans alone than for the soybeans in the soybean-wheat mixture.

In table 7 are contained the amounts of total nitrogen in the soil, tops, roots, and nodules for each pot at both harvests. An examination of this table reveals a loss of nitrogen in all cropped soil over the original and checks. The loss was greater at each harvest with the soil planted to wheat alone than with soybeans alone or with the soybean-wheat mixture. The loss for the latter was less than that for the soybean alone at the first harvest and practically the same at the second.

The soybean tops had a higher percentage of total nitrogen than the wheat tops. The percentage of nitrogen was greater at the second harvest than at the first. The wheat tops of the soybean-wheat mixture were slightly lower in nitrogen at both harvests than the wheat alone. The wheat tops of the second harvest had a lower nitrogen content than those of the first.

The wheat roots grown in association with soybeans contained a higher percentage of nitrogen than those of wheat grown alone at both harvests. The nitrogen content of soybeans roots was slightly higher at the first than at the second harvest.

The nodules were exceptionally high in total nitrogen and those of the second harvest contained more nitrogen than those of the first. The association of soybeans with wheat did not seem to influence the nitrogen content of the nodules.

TABLE 7

Total nitrogen in soil, tops, roots, and nodules obtained in series I

POT NUMBER	TREATMENT	SOIL	TOPS	ROOTS	NODULES
		per cent	*per cent*	*per cent*	*per cent*
	First harvest				
1	Wheat	0.3094	2.14	2.08	....
2	Soybeans	0.3190	3.44	2.74	7.85
3	Wheat with soybeans	0.3254	2.02	2.15	....
4	Soybeans with wheat	0.3254	3 33	2.41	7.79
CK	Check	0.3324	....	....	....
	Second harvest				
5	Wheat	0.2881	1.93	1.53	....
6	Soybeans	0.3085	3.63	2.14	9.81
7	Wheat with soybeans	0.3087	1.88	2.55	....
8	Soybeans with wheat	0.3087	3.68	2.21	9.58
CK	Check	0.3367	....	....	....
Orig.	Original soil	0.3408	....	....	....

Series II

In this series soybeans and wheat were grown alone and in association on unsterilized Lufkin fine sandy loam. The weights of the tops, roots, nodules, and plants obtained from the first and second harvests, are given for each pot in table 8.

An examination of this table shows that the combined weight of the tops of wheat and of soybeans grown in association was greater than that of wheat but less than that of soybeans grown alone at both harvests. The combined weight of the roots of wheat and of soybeans grown in association was greater than that of soybeans but less than that of wheat grown alone at both harvests.

The average weight of nodules for each of the plants grown in association with wheat was slightly higher than for those grown alone, for the first harvest, but slightly lower for the second. The average combined weight of the plants of the soybean-wheat mixture was greater than that of wheat or soybeans grown alone at both harvests.

In table 9 are contained the amounts of ammonia, in parts per million, found in the soil, tops, roots, and nodules for each pot at both harvests. At the time of the first harvest the average ammonia content of the soil was 0.1036 p.p.m. for wheat grown alone, 0.0539 for soybeans grown alone, and 0.047 for wheat and soybeans grown in association. At the time of the second harvest the ammonia content of the soil was reversed, being a trace, 0.0093, and 0.0168 p.p.m. for wheat grown alone, for soybeans alone, and for wheat and soybeans in association, respectively.

TABLE 8

Dry weight of plants grown in unsterilized Lufkin fine sandy loam

POT NUMBER	TREATMENT	TOPS	ROOTS	NODULES	PLANTS
		gm.	*gm.*	*gm.*	*gm.*
	First harvest				
1	Wheat	8.52	10.40	....	18.92
2	Soybeans	15.80	3.76	0.79	20.36
3	Wheat with soybeans	5.85	8.10	....	13.95
4	Soybeans with wheat	8.75	1.56	0.76	11.07
	Second harvest				
5	Wheat	14.15	24.35	....	38.50
6	Soybeans	27.30	7.10	2.09	36.49
7	Wheat with soybeans	8.40	16.15	....	24.55
8	Soybeans with wheat	13.05	1.85	0.98	15.88

With the exception of the wheat tops of pot 1, in which case a poor grade of carbon black was used in decolorizing the plant extract, the wheat plants, both tops and roots, grown in association with soybeans contained more ammonia than the tops and roots of corresponding wheat plants grown alone at both harvests. The wheat tops grown in association with soybeans contained an average of 5.51 and 3.13 p.p.m. as compared with 24.94 and 1.58 p.p.m. for wheat tops grown alone at the first and second harvests, respectively. The corresponding wheat roots contained 16.70 and 1.92 p.p.m. for wheat grown in association with soybeans, and 9.60 and 0.04 p.p.m. for wheat grown alone at the first and second harvests, respectively.

The average ammonia content of soybean tops grown alone was greater with each harvest than that of soybeans grown with wheat. The soybean tops grown alone contained 10.56 and 3.39 p.p.m. as compared with 8.75 and 2.78 p.p.m. for soybean tops grown with wheat, respectively. The reverse was true

TABLE 9

Ammonia in soil, tops, roots, and nodules obtained in unsterilized Lufkin fine sandy loam series

POT NUMBER	TREATMENT	SOIL	TOPS	ROOTS	NODULES
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
	First harvest				
1*	Wheat	0.1036	24.94	9.60	.....
2	Soybeans	0.0539	10.56	14.02	48.18
3	Wheat with soybeans	0.0470	5.51	16.70	.....
4	Soybeans with wheat	0.0470	8.75	28.85	33.65
CK	Check	0.0360	....	....	.....
	Second harvest				
5	Wheat	Trace	1.58	0.04	.....
6	Soybeans	0.0093	3.39	1.43	9.91
7	Wheat with soybeans	0.0168	3.13	1.92	.....
8	Soybeans with wheat	0.0168	2.78	5.63	14.14
CK	Check	0.0039	.....	.....	.....
Orig.	Original soil	0.0062	.....	.....	.....

* The water extract of the soil and wheat tops of pot 1 were decolorized with a poor grade of carbon black which failed to remove all the coloring matter and to produce a clear solution. The readings are, therefore, too high.

TABLE 10

Nitrites in soil, tops, roots, and nodules obtained in the unsterilized Lufkin fine sandy loam series

POT NUMBER	TREATMENT	SOIL	TOPS	ROOTS	NODULES
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
	First harvest				
1	Wheat	None	None	None	.....
2	Soybeans	None	None	None	None
3	Wheat with soybeans	None	None	None	.....
4	Soybeans with wheat	None	None	None	None
CK	Check	0.0391	.....	.....	.....
	Second harvest				
5	Wheat	Trace	None	None	.....
6	Soybeans	0.0191	1.12	0.31	None
7	Wheat with soybeans	0.0362	None	0.20	.....
8	Soybeans with wheat	0.0362	0.23	6.78	None
CK	Check	Trace	.....	.....	.....
Orig.	Original soil	*	.....	.....	.....

*Reading lost.

with the roots. Soybean roots grown alone contained 14.02 and 1.43 p.p.m. of ammonia as compared with 28.85 and 5.63 p.p.m. for the corresponding plants grown with wheat. The nodules contained an abundance of ammonia in all cases, but those of the first harvest contained a much greater amount of ammonia than those of the second.

In table 10 are given the results of the nitrite determinations made on the soil, tops, roots and nodules at the first and second harvest, of the unsterilized Lufkin fine sandy loam series. An examination of this table reveals the absence of nitrites in the soil, tops, roots, and nodules at the first harvest in all samples, except the soil of the check pots.

TABLE 11

Nitrates in soil, tops, roots, and nodules obtained in the unsterilized Lufkin fine sandy loam series

POT NUMBER	TREATMENT	SOIL	TOPS	ROOTS	NODULES
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
	First harvest				
1	Wheat	0.0312	11.66	None	.....
2	Soybeans	0.0016	Trace	1.89	None
3	Wheat with soybeans	None	4.26	5.14	.....
4	Soybeans with wheat	None	3.79	None	None
CK	Check	1.8875	.....	.....	.....
	Second harvest				
5	Wheat	None	None	None	.....
6	Soybeans	None	None	None	None
7	Wheat with soybeans	None	None	None	.....
8	Soybeans with wheat	None	None	None	None
CK	Check	0.4836	.....	.....	.....
Orig.	Original soil	0.1366	.....	.....	.....

The nitrite content of the soil at the second harvest was 0.0362 p.p.m. for the soybean-wheat mixture and 0.0191 and a trace for the soybeans and wheat alone, respectively, as compared with a trace for the checks.

The tops of wheat grown alone and in association with soybeans were free from nitrites. This was also true with the roots, except for those of pot 7 in which wheat was grown with soybeans. The roots in this case contained 0.2 p.p.m. of nitrites. The soybean tops and roots contained nitrites when grown alone and in association. The nodules were free from nitrites in all samples.

The results of the nitrate determinations on the soil, tops, roots, and nodules at the first and second harvests, found in table 11, show the absence of nitrates from all nodules at both harvests and from all soil, except that of the check pots, and from all crops, tops, and roots at the second harvest. A further

examination of this table reveals the absence of any regularity in the presence or absence of nitrates in soil, tops, and roots of plants.

In table 12 are contained the results of the amino acid nitrogen determinations made on the soil, tops, roots and nodules for each pot in the unsterilized Lufkin fine sandy loam series. This table shows the absence of amino acids in all soils and in all wheat tops, and the presence of it in all soybean tops of both harvests. It was present only occasionally in the soybean and wheat roots and soybean nodules.

Table 13, which contains the amounts of total nitrogen in the soil, tops, roots, and nodules for each pot at both harvests, reveals a loss of nitrogen in all cropped soils over the original and checks. At each harvest the loss was greater in the soil planted to wheat alone than in that planted to soybeans alone or to the soybean-wheat mixture. The loss of nitrogen was greater with the soybean-wheat mixture than with the soybeans alone for the first harvest but slightly less for the second.

TABLE 12

Amino acid nitrogen in soil, tops, roots, and nodules obtained in the unsterilized Lufkin fine sandy loam series

POT NUMBER	TREATMENT	SOIL	TOPS	ROOTS	NODULES
		cc. N	*cc. N*	*cc. N*	*cc. N*
	First harvest				
1	Wheat	None	None	0.08	.....
2	Soybeans	None	0.47	None	None
3	Wheat with soybeans	None	None	None	.....
4	Soybeans with wheat	None	0.47	None	2.67
CK	Check	None	.....	.....	.....
	Second harvest				
5	Wheat	None	None	None	.....
6	Soybeans	None	0.53	None	0.88
7	Wheat with soybeans	None	None	0.17	.....
8	Soybeans with wheat	None	0.70	None	None
CK	Check	None	.....	.....	.....
Orig.	Original soil	None	.....	.....	.....

With the exception of the wheat tops in pot 1 the soybean tops had a higher percentage of nitrogen than the corresponding wheat tops. The tops and the roots of the wheat grown with soybeans contained a higher percentage of nitrogen than those grown alone, and those of the soybeans grown alone showed a higher percentage than those of soybeans grown with wheat.

The nodules of this series were higher in nitrogen than those of series III, but much lower than those of series I, in which Carrington loam soil was used.

The average total nitrogen in the nodules was slightly higher for the soybeans grown alone than for those grown with wheat, and higher at the first harvest than at the second.

TABLE 13

Total nitrogen in soil, tops, roots, and nodules obtained in the unsterilized Lufkin fine sandy loam soil series

POT NUMBER	TREATMENT	SOIL	TOPS	ROOTS	NODULES
		per cent	*per cent*	*per cent*	*per cent*
	First harvest				
1	Wheat	0.0663	3.18	1.30	....
2	Soybeans	0.0739	2.50	1.60	4.04
3	Wheat with soybeans	0.0694	2.09	1.13	....
4	Soybeans with wheat	0.0694	2.32	1.37	3.99
CK	Check	0.0641	....	....	....
	Second harvest				
5	Wheat	0.0632	1.30	0.85	....
6	Soybeans	0.0684	2.25	1.66	3.83
7	Wheat with soybeans	0.0694	1.84	0.96	....
8	Soybeans with wheat	0.0694	1.98	1.62	3.71
CK	Check	0.0744	....	....	....
Orig.	Original soil	0.0788	....	....	....

TABLE 14

Dry weight of plants grown in sterilized Lufkin fine sandy loam

POT NUMBER	TREATMENT	TOPS	ROOTS	NODULES	PLANTS
		gm.	*gm.*	*gm.*	*gm.*
	First harvest				
1	Wheat	5.26	11.35	....	16.60
2	Soybeans	6.60	2.39	0.23	9.22
3	Wheat with soybeans	2.33	2.87	....	5.21
4	Soybeans with wheat	5.45	1.05	0.26	6.77
	Second harvest				
5	Wheat	6.95	25.60	....	32.55
6	Soybeans	8.85	2.18	0.28	11.31
7	Wheat with soybeans	3.71	5.19	....	8.90
8	Soybeans with wheat	8.10	1.60	0.41	10.11

Series III

In this series soybeans and wheat were grown alone and in association on sterilized Lufkin fine sandy loam. The weights of tops, roots, nodules, and plants secured are given for each pot in table 14. An examination of the

yields in this table shows that the combined weight of the tops of wheat and soybeans grown in association was greater than that of wheat and of soybeans grown alone. The combined weight of the roots and plants of wheat and soybeans grown in association was greater than that of soybeans but less than that of wheat grown alone. The average weight of the nodules from soybeans grown with wheat was greater than that of nodules from soybeans grown alone at both harvests.

Table 15 gives the amounts of ammonia in the soil, tops, roots, and nodules for each pot at both harvests. Here, as with the data for the soil and tops of pot 1 in table 9, series II, the readings of ammonia for soil, tops, and roots of

TABLE 15

Ammonia in soil, tops, roots, and nodules obtained in the sterilized Lufkin fine sandy loam series

POT NUMBER	TREATMENT	SOIL	TOPS	ROOTS	NODULES
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
	First harvest				
1*	Wheat	0.0865	20.54	12.20	.....
2	Soybeans	0.0391	4.62	10.38	29.64
3	Wheat with soybeans	0.0322	6.10	7.11	.....
4	Soybeans with wheat	0.0322	4.63	11.42	34.00
CK	Check	0.0518	.....	.....	.....
	Second harvest				
5	Wheat	None	2.50	0.28	.....
6	Soybeans	0.0429	4.41	3.96	16.00
7	Wheat with soybeans	0.0224	7.85	5.03	.....
8	Soybeans with wheat	0.0224	4.30	5.73	13.97
CK	Check	0.0104	.....	.....	.....
Orig.	Original soil	0.0835	.....	.....	.....

* The water extract of the soil and plants of pot 1 were decolorized with a poor grade of carbon black which failed to produce a clear solution. The readings of ammonia are, therefore, too high.

pot 1 were too high, because of the use of the same poor grade of carbon black for decolorizing the soil and plant extracts. With this exception the tops and roots of the wheat plants grown in association with soybeans contained larger amounts of ammonia than those of the wheat plants grown alone. The wheat tops grown in association with soybeans contained an average of 6.10 and 7.85 p.p.m. of ammonia, whereas the tops of the wheat grown alone in corresponding pots contained 20.54 and 2.50 p.p.m. for the first and second harvests, respectively. With one exception the wheat tops contained a larger amount of ammonia than the corresponding soybean tops. The wheat roots corresponding to the aforementioned tops contained an average of 7.11 and

5.03 p.p.m. of ammonia for those grown with soybeans, and 12.20 and 0.28 p.p.m. for those grown alone. With one exception, the soybean roots contained a larger amount of ammonia than the corresponding wheat roots. The nodules showed an abundance of ammonia in all cases.

With the exception of the soil of pot 1, the ammonia content of the wheat soil was lower than that of the soybean-wheat mixture and of the soybeans alone at both harvests. The soybean soil had more ammonia than the soil of the soybean-wheat mixture.

Table 16 gives the results of the nitrite determinations made on the soil, tops, roots, and nodules at the first and second harvests of the sterilized Lufkin fine sandy loam series. An examination of this table reveals the absence of nitrites from all cropped soils, except one wheat and one soybean soil. The

TABLE 16

Nitrites in soil, tops, roots, and nodules obtained in the sterilized Lufkin fine sandy loam series

POT NUMBER	TREATMENT	SOIL	TOPS	ROOTS	NODULES
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
	First harvest				
1	Wheat	0.0186	None	None	.....
2	Soybeans	None	None	None	None
3	Wheat with soybeans	None	None	None	.....
4	Soybeans with wheat	None	None	None	None
CK	Check	Trace	.....	.....	.....
	Second harvest				
5	Wheat	None	None	None	.....
6	Soybeans	0.0023	0.03	1.63	6.62
7	Wheat with soybeans	None	0.14	0.70	.....
8	Soybeans with wheat	None	0.11	1.57	2.36
CK	Check	0.0008	.....	.....	.....
Orig.	Original soil	0.1746	.....	.....	.....

amount of nitrites present in these soils was very small. Nitrites were absent from all samples of plants at the first harvest.

The tops and roots of wheat grown alone at the second harvest were free from nitrites, whereas those of the soybean-wheat mixture showed fairly large amounts. The soybean tops of this harvest contained small amounts of nitrites, whereas nitrites were present in fairly large quantities in the roots and nodules of the soybean plants. The average nitrite content of the roots and nodules of soybeans grown alone was greater than that of soybeans grown with wheat.

The results for the nitrate determinations on the soil, tops, roots, and nodules for each pot in series III are found in table 17. An examination of the results in this table shows that nitrates were present in only one cropped soil,

in the checks, and in the original. A further examination of this table reveals the fact that nitrates were also absent from all soybean and wheat tops, as well as from the wheat roots and from the soybean nodules of both harvests. Nitrates were present only in the soybean roots from pots 4, 6, and 8.

In table 18 are presented the results of the amino acid determinations made on the soil, tops, roots, and nodules for each pot in the sterilized Lufkin fine sandy loam series. An examination of this table shows that amino acids were absent from all soil, from all wheat tops, and from all soybean nodules of both harvests, whereas they were present in all soybean tops of both harvests and in the roots of pots 2, 3, and 4.

Table 19 contains the amounts of total nitrogen in soil, tops, roots, and nodules for each pot in series III. An examination of this table reveals a

TABLE 17

Nitrates in soil, tops, roots, and nodules obtained in the sterilized Lufkin fine sandy loam series

POT NUMBER	TREATMENT	SOIL	TOPS	ROOTS	NODULES
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
	First harvest				
1	Wheat	0.0376	None	None	.....
2	Soybeans	None	None	None	None
3	Wheat with soybeans	None	None	None	.....
4	Soybeans with wheat	None	None	4.38	None
CK	Check	0.3733	.....	.....	.....
	Second harvest				
5	Wheat	None	None	None	.....
6	Soybeans	None	None	4.21	None
7	Wheat with soybeans	None	None	None	.....
8	Soybeans with wheat	None	None	1.76	None
CK	Check	0.2295	.....	.....	.....
Orig.	Original soil	0.0364	.....	.....	.....

loss of nitrogen from all soils over the original. The loss was less at each harvest in the soils planted to wheat than in those planted to wheat and soybeans in association, or to soybeans alone. The loss was much greater at the second harvest than at the first. The difference between the loss of nitrogen from the soils planted to wheat and soybeans in association and to soybeans and wheat alone was very slight. The tops and roots of wheat grown in association with soybeans had a higher percentage of nitrogen than the tops and roots of corresponding wheat plants grown alone.

The nitrogen content of the nodules was higher than that of the tops and roots of the soybean plants, but much lower on the average than that for the nodules of the unsterilized soil in series II. The nodules of the second harvest were lower in nitrogen than those of the first.

TABLE 18

Amino acid nitrogen in soil, tops, roots, and nodules obtained in the sterilized Lufkin fine sandy loam series

POT NUMBER	TREATMENT	SOIL	TOPS	ROOTS	NODULES
		cc. N	*cc. N*	*cc. N*	*cc. N*
	First harvest				
1	Wheat	None	None	None	.....
2	Soybeans	None	0.5200	1.12	None
3	Wheat with soybeans	None	None	0.20	.....
4	Soybeans with wheat	None	0.1300	0.76	None
CK	Check	None	.....	.....	.....
	Second harvest				
5	Wheat	None	None	None	.....
6	Soybeans	None	0.7600	None	None
7	Wheat with soybeans	None	None	None	.....
8	Soybeans with wheat	None	0.1600	None	None
CK	Check	None	.....	.....	.....
Orig.	Original soil	None	.....	.....	.....

TABLE 19

Total nitrogen in soil, tops, roots, and nodules obtained in the sterilized Lufkin fine sandy loam series

POT NUMBER	TREATMENT	SOIL	TOPS	ROOTS	NODULES
		per cent	*per cent*	*per cent*	*per cent*
	First harvest				
1	Wheat	0.0717	2.11	0.65	....
2	Soybeans	0.0614	2.96	1.69	3.94
3	Wheat with soybeans	0.0630	2.17	1.38	....
4	Soybeans with wheat	0.0630	2.53	2.57	3.65
CK	Check	0.0750	....	....	....
	Second harvest				
5	Wheat	0.0695	1.27	0.65	....
6	Soybeans	0.0471	2.60	1.53	2.36
7	Wheat with soybeans	0.0459	1.61	0.79	....
8	Soybeans with wheat	0.0459	2.30	1.15	3.15
CK	Check	0.0671	....	....	....
Orig.	Original soil	0.0788	....	....	....

Series IV

In this series soybeans were grown in nitrogen-free sand. Pots 1 and 2 were uninoculated while pots 3 to 8 inclusive were inoculated. The plants in pots 1 and 2 were harvested as soon as growth ceased, because of the exhaustion of the reserve food in the cotyledons. The plants of pots 3 and 4 were cut at the time when they were just recovering from the period of "nitrogen hunger." The roots and sand immediately around the roots were analyzed for the various forms of water-soluble nitrogen recorded in tables 20 to 25. The system of numbering the pots in the tables of this series was as follows: pot 1 includes uninoculated pots 1 and 2; pot 2, inoculated pots 3 and 4; pot 3, inoculated pots 5 and 6; and pot 4, inoculated pots 7 and 8. The results given in the tables are the averages of duplicate determinations on duplicate pots. The plants in pots 5 and 6 were harvested when the first blooms appeared and those of pots 7 and 8 when the first pods were about half mature. The sand, tops, roots, and nodules were analyzed for the same forms of nitrogen reported in the soil series.

The weights of tops, roots, nodules, and plants secured for each pot in series IV (table 20) show that the inoculated plants made a satisfactory growth in the nitrogen-free sand. The average yields of tops, roots, nodules, and plants increased with the age of the plant.

Table 21, which contains the amounts of ammonia in the sand, tops, roots, and nodules for each pot in series IV, shows that ammonia was present in all samples of sand and crops. The most striking feature of this table was that the sand and roots of the uninoculated pot 1 had a much higher ammonia content than those of the inoculated pots. This may be accounted for, however, by the fact that it was difficult to tell just when active growth ceased and when decomposition of the small rootlets set in with the uninoculated plants. The excessive amounts of ammonia may have been due to the ammonification of the small rootlets and may have represented the ammonia contained in the seed planted. The ammonia content of the sand was greatest with pot 1 and smallest with pot 4. The ammonia content of the sand of the inoculated pots decreased with the age of the plants.

Ammonia determinations were not made on the tops of plants in pots 1 and 2. The tops of the plants of the remaining pots showed the presence of ammonia in all cases, the average ammonia content being practically the same at both harvests.

There was a striking similarity between the ammonia content of the sand and of the roots of all pots. The roots of the uninoculated soybean plants contained an average of 60.49 p.p.m. of ammonia as compared with 12.98, 4.00, and 4.27 p.p.m. for those of the soybeans harvested at the "nitrogen hunger," "first bloom," and "first pods half mature" stages, respectively.

The nodules of pots 3 and 4 showed the presence of ammonia, the amount being slightly higher for pot 3 than for pot 4.

TABLE 20

Dry weight of plants grown in the nitrogen-free sand series

POT NUMBER	TREATMENT	TOPS	ROOTS	NODULES	PLANTS
		gm.	*gm.*	*gm.*	*gm.*
1	Soybeans, uninoculated	.....	0.34	....	.....
2	Soybeans, inoculated	.....	0.89	....	.....
3	Soybeans, inoculated	10.77	3.55	1.35	15.68
4	Soybeans, inoculated	13.30	3.62	1.69	18.62

TABLE 21

Ammonia in sand, tops, roots, and nodules obtained in the nitrogen-free sand series

POT NUMBER	TREATMENT	SAND	TOPS	ROOTS	NODULES
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
1	Soybeans, uninoculated	0.1425	....	60.49	....
2	Soybeans, inoculated	0.0928	....	12.98	....
3	Soybeans, inoculated	0.0560	3.86	4.00	5.46
4	Soybeans, inoculated	0.0510	3.88	4.27	5.16

TABLE 22

Nitrites in sand, tops, roots, and nodules obtained in the nitrogen-free sand series

POT NUMBER	TREATMENT	SAND	TOPS	ROOTS	NODULES
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
1	Soybeans, uninoculated	Trace	....	None	....
2	Soybeans, inoculated	None	....	Trace	....
3	Soybeans, inoculated	0.0129	0.66	0.52	0.85
4	Soybeans, inoculated	0.0067	0.35	0.50	0.83

TABLE 23

Nitrates in sand, tops, roots, and nodules obtained in the nitrogen-free sand series

POT NUMBER	TREATMENT	SAND	TOPS	ROOTS	NODULES
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
1	Soybeans, uninoculated	0.0175	.....	None	.....
2	Soybeans, inoculated	0.0125	.....	28.30	.....
3	Soybeans, inoculated	None	None	None	None
4	Soybeans, inoculated	None	None	None	None

TABLE 24

Amino acid nitrogen in sand, tops, roots, and nodules obtained in the nitrogen-free sand series

POT NUMBER	TREATMENT	SAND	TOPS	ROOTS	NODULES
		cc. N	*cc. N*	*cc. N*	*cc. N*
1	Soybeans, uninoculated	None	....	None	.....
2	Soybeans, inoculated	None	....	None	.....
3	Soybeans, inoculated	None	1.37	0.43	None
4	Soybeans, inoculated	None	1.37	0.35	None

Table 22 reveals only a trace of nitrites in the sand and "none" in the roots of the uninoculated pot. The sand of pot 2 was free from nitrites, whereas the roots contained only a trace. The sand, tops, roots, and nodules of pot 3 showed a greater nitrite content than did those of pot 4.

Table 23 shows that nitrates were absent from the sand, tops, roots, and nodules in all samples, except from the sand in pots 1 and 2 and from the roots in pot 2.

Table 24 shows that amino acids were absent from the sand and nodules of all pots, and also from the roots of pots 1 and 2. The soybean tops and roots of pots 3 and 4 revealed small quantities of amino acid nitrogen.

Table 25 shows the total nitrogen determinations for the sand, tops, roots, and nodules of pots 3 and 4. An examination of this table reveals a decided gain or fixation of nitrogen in the sand. It also shows the fact that the tops, roots, and nodules of the soybean plants contained a high percentage of nitrogen in all cases.

TABLE 25

Total nitrogen in sand, tops, roots, and nodules obtained in the nitrogen-free sand series

POT NUMBER	TREATMENT	SAND	TOPS	ROOTS	NODULES
		per cent	*per cent*	*per cent*	*per cent*
1	Soybeans, uninoculated.........	......	....	....	....
2	Soybeans, inoculated...........	......	....	....	....
3	Soybeans, inoculated...........	0.0163	2.74	2.64	4.34
4	Soybeans, inoculated...........	0.0150	2.93	2.91	4.51

DISCUSSION OF RESULTS

It may easily be seen from the data presented in this paper that some of the problems discussed have no direct bearing on the main object of the experiment, but they are very closely related and may supplement available data.

A careful study of the portion of the data bearing directly upon the object of this paper discloses some very interesting occurrences which, even though they may be applicable only to the conditions under which the experimental work was conducted and not to field conditions in general, if not in themselves a solution of the problem, may prove helpful in arriving at a satisfactory one.

The data presented in the foregoing pages may be summarized briefly here in order to direct attention to their more salient points.

The weights and total nitrogen of the tops, roots, nodules, and plants were of no particular significance insofar as this problem was concerned.

Ammonia was present in greater or less amounts in all samples of soil, tops, roots, and nodules of each pot in the four series. The wheat soils of both harvests of the Carrington loam and those of the first harvest of the two Lufkin fine sandy loam series had a higher ammonia content than those planted to wheat and soybeans grown in association or to soybeans alone. With one or

two exceptions there was but little difference in the ammonia content of soils planted to the soybean-wheat mixture and to soybeans alone in series I, II, and III.

With the exception of the wheat tops of the first harvest of series II and the wheat tops and roots of the same harvest of series III, in which cases a poor grade of carbon black was used to decolorize the plant extracts, the tops and roots of wheat grown in association with soybeans contained a higher ammonia content than those of corresponding wheat plants grown alone. The regularity of this difference may be a peculiar coincidence and may have no bearing on the immediate solution of the problem, but it is very striking indeed when considered in the light of a more complete discussion of the ammonia data presented here. In all instances the roots of soybeans grown with wheat contained a higher ammonia content than those of corresponding soybeans grown alone. Should the wheat plants obtain nitrogen from the soybeans in the form of ammonia their association with the latter evidently served to stimulate the production of ammonia by the soybean plant through the assistance of the nodule bacteria. With the exception of the first harvest of the sterilized Lufkin fine sandy loam series, the tops of the soybeans grown alone contained more ammonia than those of corresponding soybean plants grown with wheat. In this case the ammonia content of the soybean tops grown alone was practically the same as that of the soybean tops grown with wheat.

These data indicate that the wheat plants grown in association with soybeans had the ability to stimulate ammonia production, assimilation, or accumulation in the roots of the soybean plants. It is possible that the close relationship existing between the root systems of the two plants was such as to stimulate ammonia production by the legume bacteria. Assuming this to be the case the remaining portion of this peculiar phenomenon could be explained by the electrical theory of plant feeding, that is, if plants are capable of feeding by the electrical absorption of plus or minus ions from the soil solution, as governed by the state of equilibrium of these charges within the plant juices, it seems equally possible that if the wheat plant was capable of setting up a stronger attraction for the ammonia radicle than the soybean the wheat plant would be able to obtain it even though it were already in the roots of the soybean plants. This, of course, would mean that the ammonia, which was produced in the soybean roots, would be removed to the wheat plant instead of being allowed to pass further into the soybean plant.

The nodules contained an abundance of ammonia in all cases, the amount in each series being much greater at the first harvest than at the second. Ammonia was also present in the sand, tops, roots, and nodules of the soybeans from each pot in the nitrogen-free sand series. The sand and soybean roots from the uninoculated pot of this series contained more ammonia than those from the inoculated pots. The ammonia content of the sand and soybean roots of pot 2, harvested at the time when the plants were just recovering from the period of "nitrogen hunger," was much greater than that of pots

3 and 4 which were harvested at later periods. There were but slight differences between the ammonia content of the sand, tops, roots, and nodules of those pots harvested at the last two stages of growth.

The data obtained on nitrite nitrogen were not nearly as interesting as those of ammonia. Nitrites were present in all soils, tops, roots, and nodules of each pot in the Carrington loam series. The amount present was much larger in the soils and roots of the second harvest than those of the corresponding soils and roots of the first, and much smaller for the tops and nodules of the second than for those of the first. In contrast with this, nitrites were absent from all cropped soils of the sterilized Lufkin fine sandy loam at the first harvest, except that planted to wheat alone, and all of the unsterilized Lufkin fine sandy loam at the first harvest. The differences found here may possibly have been due to the difference in the fertility of the two types of soil.

The wheat soils of the second harvest had a trace and "none" of nitrites in series II and III, respectively. The soils of series II, in which soybeans and wheat were grown both in association and alone, contained small amounts of nitrites whereas series III contained nitrites only in the soils where soybeans were grown alone. All tops and roots of soybeans and the wheat roots of the soybean-wheat pots, of the second harvest of series II, showed nitrites to be present, whereas the other wheat roots showed them to be absent. Nitrites were present in the tops and roots of soybeans grown alone, and with wheat, and in those of wheat grown with soybeans at the second harvest of series III. They also occurred in the nodules of the second harvest of this series.

The sand of uninoculated pot 1 of the nitrogen-free sand series showed a trace of nitrites whereas that of the inoculated pot 2 did not. Nitrites were absent from uninoculated roots but were present in traces only in the roots of the inoculated pots 3 and 4 of this series. Notwithstanding the fact that nitrites occurred in all samples of inoculated soybean roots, tops and nodules of the nitrogen-free sand series, they did not always occur in similar parts of inoculated soybeans grown in the sterilized and in the unsterilized Lufkin fine sandy loam.

Nitrates were present in all soils and samples of tops and roots of wheat and soybeans in series I. They were absent from all nodules in this as well as the other three series. Nitrates were present in small amounts only in the soil in which wheat and soybeans were grown alone at the first harvest in series II, and in wheat soils of series III of the same harvest. Nitrates were present in the tops of wheat and soybeans grown alone and in association, and in the roots of soybeans grown alone, and those of wheat grown with soybeans at the first harvest of series II. All tops and roots of the second harvest of series II were free from nitrates.

In the sterilized Lufkin fine sandy loam series, nitrates were absent from all soybean and wheat tops. They were present only in the roots of soybeans of the soybean-wheat mixture of the first harvest, and in those of the soybeans grown alone and with wheat of the second.

Nitrates were present in the sand of pots 1 and 2 and the soybean roots of

pot 2 of the nitrogen-free sand series. In all other pots of this series nitrates were absent from the sand, tops, roots, and nodules.

It seems that the complete absence of nitrates from all samples of nodules and their irregular occurrence in the soil and in the tops and roots of soybeans would minimize their importance in this problem.

Amino acid nitrogen was absent from all soils in series I and III inclusive, and from the sand of series IV, and present in all samples of soybean tops of the four series. It was also present in all samples of roots of series I. All wheat tops of series II and III and all roots of series II, except those of wheat grown alone at the first harvest and those of wheat grown with soybeans at the second, were free from amino acid nitrogen. The soybean nodules of series II grown in association with wheat at the first harvest, and alone at the second, showed the presence of small quantities of amino acid nitrogen. In series III amino acid nitrogen was absent from all roots at the second harvest and from all nodules at both harvests of this series as well as from the nodules of series IV. Amino acid nitrogen was present in small amounts in the soybean roots of series IV.

CONCLUSIONS

The data obtained from these experiments seem to justify the following conclusions:

1. Ammonia was found in all soils, tops, roots and nodules of each pot in the four series.

2. With the exception of the wheat tops grown alone at the first harvest of series II and of the tops and roots of wheat grown alone at the same harvest of series III, the tops and roots of wheat grown in association with soybeans had a higher ammonia content than those of corresponding wheat plants grown alone.

3. The roots of soybeans grown in association with wheat contained a larger amount of ammonia than those of corresponding soybean plants grown alone.

4. The sand and soybean roots of the uninoculated pots of the nitrogen-free sand series contained more ammonia than did those of the inoculated pots.

5. Nitrites were found in all tops and nodules and in all roots of the inoculated pots of the nitrogen-free sand series.

6. Nitrates were not found in soybean nodules of any series, but were sometimes found in the roots of inoculated soybeans grown in nitrogen-free sand.

7. Amino acid nitrogen was not found in the soil or nitrogen-free sand, but it was found in all soybean tops of the four series, and was sometimes found in soybean nodules, in soybean and wheat roots, and in wheat tops.

8. Wheat grown in association with inoculated soybeans may, under favorable conditions, obtain considerable amounts of nitrogen from the latter without lowering the nitrogen content of the soybeans.

9. Soybeans were capable of fixing large amounts of nitrogen when grown in inoculated nitrogen-free sand.

10. Ammonia was the only form of water-soluble nitrogen found in the soil tops, roots, nodules, and nitrogen-free sand of each pot in the four series.

11. The beneficial influence exerted upon wheat by the inoculated soybeans was evidently due to soluble nitrogen, possibly ammonia, placed at the disposal of the latter by the former, when grown in association.

12. All cropped soils showed a loss of nitrogen. With the unsterilized soil this loss was greater in the soil planted to wheat alone than in the soils planted to soybeans and wheat in association or to soybeans alone, whereas in the sterilized Lufkin fine sandy loam series the loss from the soil planted to wheat alone was less than from the soil planted to soybeans and wheat in association or to soybeans alone.

EFFECTS OF SOIL TREATMENTS UPON THE DRAFT OF PLOWS[1]

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An experiment field, now known as Sanborn field, comprising 39 plots was established at the Missouri Experiment Station in 1888 (4) on a phase of the Putnam silt loam. This field was designed primarily for studying the effects of crop rotation, of manuring, and of the use of chemical fertilizer upon the yields of crops. Because, however, of the long continued application of the same soil treatments, which differ for each plot, some of these plots have become vastly different from others both in productiveness and in physical, chemical, and biological properties. They therefore provide an excellent opportunity for making special studies concerning the effects of various soil treatments when continued throughout a long period of time.

For a number of years it has been observed that the manured plots have not worked down into as friable a seedbed as has the untreated land or the land receiving chemical fertilizers. No very satisfactory method was known for measuring this difference or for expressing it in mathematical terms. It was thought, however, that measurements of the draft of plows might show whether the manure actually made the soil harder to work. Accordingly dynamometer tests were begun on some of these plots in 1923—34 years after the soil treatments were started. Because some of the plots with the longer rotations are not plowed very often a good deal of time is required to accumulate any considerable number of measurements. Hence, this paper is presented as a progress report.

METHODS

The plowing was done during 1923 with a 14-inch Oliver Sulky plow and during 1924 and 1925 with a 16-inch P and O Sulky plow. Each plow was equipped with a general purpose bottom. The edge of the plot was opened with a two-way plot plow and measurements were made on the central portion of each plot. In most cases six or more readings were taken and the results averaged. The draft was determined by means of an Iowa integrating dynamometer. Some difficulty was experienced in getting an accurate measure on the depth of furrow, but the most satisfactory method found was to take an average of 8 to 12 measurements at 4- to 6-foot intervals over the

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50 feet of furrow included in each draft determination. In order to study the effect of the moisture upon the draft and upon the pulverizing effect, soil samples were taken from each plot at the time of plowing.

RESULTS OF DRAFT TESTS

Table 1 shows a summary of all the tests made, giving the average draft per square inch of furrow slice for each date. It will be noted that some of the plots vary widely at different plowings. This usually can be explained by the moisture content at the time of plowing or by the crop preceding. Most of the measurements have been made, however, upon plots having a single crop system. Plots 12 and 13 in the 6-year rotation series were plowed after oats. Plots 34, 35, 37, 38, and 39 in the 4-year rotation were plowed before corn in 1923 and before wheat in 1924. Plots 25 and 28, having a 3-year rotation, were plowed before corn in 1925. The first tests made on April 8, 1925 were at a higher moisture content than those made May 6. A slight source of error on these as well as on a few of the others was due to a light growth of weeds which may have affected the draft somewhat. An attempt was made to take the readings at all times as soon after removing a crop as possible so as to eliminate any error due to weed growth.

EFFECT OF MANURE

The effect of barnyard manure upon the draft is shown graphically in figure 1, in which manured plots have been compared with unmanured plots having the same crop treatment. In the case of plots 28 and 35 the land has been manured during the first 25 years, but has had no manure since. These have been used as unmanured plots for comparison with those continually manured. Plot 39 was not used in this case because it was located a considerable distance from 34. It should be noted also that plot 2, which received chemical fertilizer, has been used as an unmanured plot for comparison with no. 5. It must be remembered that these plots are comparable in pairs—manured vs. unmanured.

The upper part of figure 1 shows the results from 15 pairs of plots. In 5 cases the manured land gave a lower draft and in 10 cases it gave a higher draft than the unmanured land. When the results from each plot taken at different times are averaged the lower curves in the figure are obtained. These show that only in the case of plots 9 and 10, which are in wheat continually, was the draft decidedly lower on the manured land. Plot 13 shows a somewhat similar difference, but this was the result of but one test, as may be seen from table 1.

Noll's (5) results at Pennsylvania show a slight decrease in draft on the manured plots when these are compared with the untreated land. However, in comparing the draft with "humus" content (C $\times$ 1.724), plot 22 having the highest amount of so-called "humus" gave an average of 455 pounds, the

TABLE 1

Effect of soil treatment upon the draft of plows

PLOT	TREATMENT	DRAFT PER SQUARE INCH OF FURROW SLICE						
		April 11, 1923	July 31, 1923	April 25, 1924	July 21, 1924	April 8, 1925	May 6, 1925	Average
2	Wheat annually Nitrate of soda 495.6 pounds per acre Acid phosphate 111.3 pounds per acre Muriate of potash 111.3 pounds per acre		5.46		6.08			5.77
5	Wheat annually Manure 6 tons 1889–1913 Manure 3 tons since 1914		6.35		6.24			6.29
9	Wheat annually No treatment		5.30		5.53			5.41
10	Wheat annually Manure 6 tons		5.26		4.84			5.05
12	6-year rotation Manure 6 tons 1889–1913–3 tons since 1913 Bonemeal 200 pounds on corn and on wheat		5.20					5.20
13	6-year rotation No soil treatment		5.67					5.67
17	Corn annually No treatment	4.63		5.60		5.43	5.80	5.36
18	Corn annually Manure 6 tons	5.04		6.82		5.02	6.29	5.74
21	Wheat annually Manure 1889–1913 Acid phosphate 200 pounds per acre since 1914				4.76			4.76
24	Wheat annually Manure 1889–1913 No treatment since 1913				4.60			4.60
34	4-year rotation Manure 6 tons	5.16			5.58			5.37
35	4-year rotation Manure 1889–1913 No treatment since 1913	5.00			5.52			5.26
37	4-year rotation Manure 6 tons 1889–1913 Fertilizer since 1913 300 pounds 3–10–4 on corn 200 pounds 3–10–4 on wheat	4.78			5.62			5.20
38	4-year rotation Same treatment as plot 37 but has 2 tons limestone with corn	4.78			5.64			5.21
39	4-year rotation No treatment	5.03			6.20			5.61

TABLE 1—*Continued*

PLOT	TREATMENT	DRAFT PER SQUARE INCH OF FURROW SLICE						
		April 11, 1923	July 31, 1923	April 25, 1923	July 21, 1924	April 8, 1925	May 6, 1925	Average
25	3-year rotation Manure 6 tons annually					4.74	5.70	5.22
26	3-year rotation Manure 9 tons on corn					4.29	5.29	4.79
27	3-year rotation No soil treatment					4.57	5.03	4.80
28	3-year rotation Manure 6 tons 1889–1913 No treatment since 1913					4.56	5.06	4.86

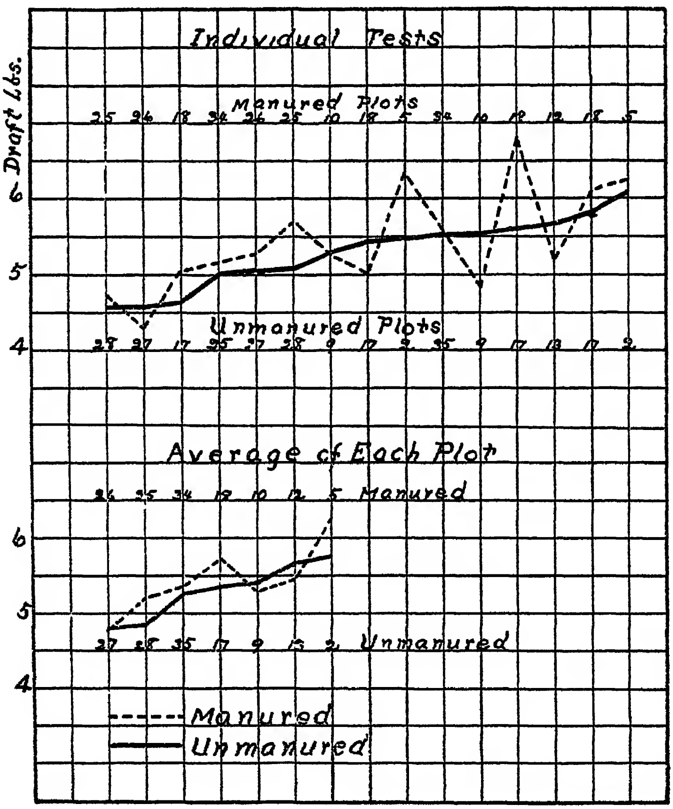

FIG. 1. COMPARISON OF THE PLOW DRAFT PER SQUARE INCH OF FURROW SLICE ON MANURED VS. UNMANURED LAND

highest draft of any of the plots; plots 20 and 21 having the next highest amount averaged 443 pounds; and plots 23 and 24 having the lowest "humus" content averaged 439 pounds.

The only explanation that can be suggested at this time as to why manure should increase the draft, is the influence exerted by the organic colloids. It seems likely that these may exert a binding effect upon the soil particles of this silt loam soil; that is, the material in an advanced stage of decomposition may exert a greater influence in binding the particles together than the undecomposed material can exert in holding them apart. As a result, the silt loam acquires some of the properties of a heavier soil and the effect upon the draft may be much the same as if clay particles had been added to the soil.

EFFECT OF FERTILIZERS AND LIME

It is a common opinion among farmers that fertilizers added to the soil will soon result in more compact soil conditions and consequent higher draft

TABLE 2

Relative effect of manure and fertilizers upon the draft of plows (4-year rotation series)

PLOT	TREATMENT	DRAFT PER SQUARE INCH APRIL 11, 1923	DRAFT PER SQUARE INCH JULY 31, 1924	AVERAGE
		pounds	*pounds*	*pounds*
34	Manure 6 tons annually 1889–1924 (35 years)	5.16	5.58	5.37
35	Manure 1889–1914 (25 years) no manure since	5.00	5.52	5.26
37	Manure 25 years, 500 pounds 3–10–4 fertilizer per rotation since	4.78	5.62	5.20
38	Same treatment as 37 + limestone 2 tons added with corn since 1914	4.78	5.64	5.21
39	No soil treatment	5.03	6.20	5.61

of plows. Some of the plots in the 4-year rotation series were manured for only the first 25 years. Fertilizers were added to one of these and fertilizer and lime were added to another. The results are shown in table 2. It will be seen that the manured land has given slightly heavier draft than the land having no manure since 1913, and furthermore the fertilized land was slightly easier to plow than the land having no fertilizer. The average results of each of plots 34 to 38 compared with 39 show that the draft on plot 39 is slightly higher. This is due chiefly to the result of 1924, a very wet season. Plot 39 being on the lower end of the series was, therefore, in a rather compact condition. Then too it is a rather long distance from plot 34 which has been manured heavily. For these reasons and particularly since it had the same treatment as the others up to 1913, plot 35 is believed to be more suitable than 39 as a check plot for determining the effect of fertilizers or manure on these plots.

A comparison of plot 2 with plot 5 in table 1 shows a similar effect of fertilizer. The former, which received chemical fertilizers, gave an average draft of 5.77 pounds whereas the latter, which received 6 tons of manure annually from 1889 to 1913 and 3 tons annually since that time, gave an average draft of 6.29 pounds. There was no untreated plot that could be compared directly with these but the results indicate that the draft was increased by the manure over the plot with chemical fertilizers. These plots, however, do not lie side by side and there is a very slight difference in slope. It seems likely, therefore, that too much emphasis should not be placed upon the results from these two plots. The figures, however, bear out the observations upon the land, since plot 2, which receives chemical fertilizers, invariably pulverizes into a much finer seedbed than does plot 5, which receives 3 tons of manure annually.

Noll (5) showed that on the Pennsylvania plots the draft was about the same on four manured plots as on plots receiving commercial fertilizer alternating with them.

The addition of lime at the rate of 2 tons an acre once in the rotation has apparently had no effect in decreasing the draft on this soil as shown by a comparison of plots 37 and 38 in table 2. This does not agree with Noll's results since he found a slight decrease in the draft due to a similar application of lime but through a longer period of years. Russell and Keen (8) also showed that 20 loads of fine chalk or 50 loads of "dug" chalk per acre reduced the draft of plows approximately 11 per cent. These are of course much heavier applications than are considered practical in America, and with relatively small amounts of liming material the effect upon draft cannot be expected to be so great.

EFFECT OF SOIL MOISTURE

Whenever dynamometer tests were made samples were taken for moisture determinations. It was believed that the effect of moisture upon draft might be considerable and that this was likely to be an important factor in causing variation under different soil treatments. Table 3 gives the moisture content of each plot at the time of the various tests. Figure 2 shows the relation between the moisture content of the soil and the draft of the plow at the time of each series of tests. It will be noted that in general the draft becomes less with the higher moisture contents, and higher whenever the ground becomes dry. Just how wide is the range of soil moisture, to which this general statement could be applied is not known, but it seems likely that it will apply fairly well on this soil to such moisture conditions as are satisfactory for plowing.

Kuhne (3) found that the draft increased with increasing dampness of a sand soil up to a certain point and thereafter decreased. In a soil dampened irregularly, the draft increased as the soil became drier. Ringelmann (7) found that for plowing, the best results were obtained when the soil which

TABLE 3

Soil moisture content of the various plots at the time dynamometer tests were made

PLOT	TREATMENT	SOIL MOISTURE					
		April 11, 1923	July 31, 1923	April 25, 1924	July 31, 1924	April 8, 1925	May 6, 1925
		per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
2	Wheat annually Nitrate of soda 495.5 pounds per acre Acid phosphate 111.3 pounds per acre Muriate of potash 111.3 pounds per acre		14.24		15.12		
5	Wheat annually Manure 6 tons 1889–1913 Manure 3 tons since 1914		12.55		24.25		
9	Wheat annually No treatment		10.66		20.79		
10	Wheat annually Manure 6 tons		19.38		27.13		
12	6-year rotation Manure 6 tons 1889–1913, 3 tons since 1913 Bonemeal 200 pounds on corn and wheat		12.63				
13	6-year rotation No soil treatment		7.09				
17	Corn annually No treatment	18.38		Lost		18.07	16.85
18	Corn annually Manure 6 tons	23.01		Lost		26.47	25.90
21	Wheat annually Manure 1889–1913 Acid phosphate 200 pounds per acre since 1914				25.78		
24	Wheat annually Manure 1889–1913 No treatment since 1913				25.19		
34	4-year rotation Manure 6 tons	28.42			27.72		
35	4-year rotation Manure 1889–1913 No treatment since 1913	20.58			25.00		
37	4-year rotation Manure 6 tons 1889–1913 Fertilizer since 1913 300 pounds 3–10–4 on corn 200 pounds 3–10–4 on wheat	26.60			25.41		
38	4-year rotation Same treatment as plot 37 but has 2 tons limestone with corn	25.60			22.21		

TABLE 3—*Continued*

PLOT	TREATMENT	SOIL MOISTURE					
		April 11, 1923	July 31, 1923	April 25, 1924	July 31, 1924	April 8, 1925	May 6, 1925
		per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
39	4-year rotation	27.10			19.93		
	No treatment						
25	3-year rotation					28.75	24.30
	Manure 6 tons annually						
26	3-year rotation					29.65	26.35
	Manure 9 tons on corn						
27	3-year rotation					25.40	24.80
	No soil treatment						
28	3-year rotation					27.55	25.80
	Manure 6 tons 1889–1913						
	No treatment since 1913						

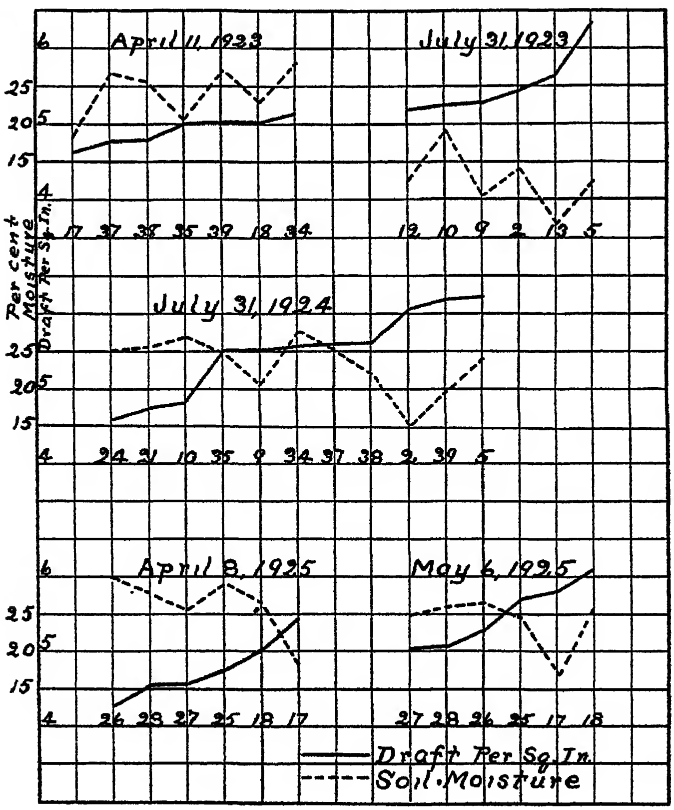

FIG. 2. RELATION BETWEEN THE PER CENT OF SOIL MOISTURE AND THE DRAFT OF PLOWS
Results on each date tests were made

was a calcareous clay contained 11 to 17 per cent of moisture, depending upon the physical character of the soil. The traction increased with decrease of moisture in the soil as follows:

MOISTURE	DRAFT PER SQUARE DECIMETER
per cent	*kgm.*
15 4	47.4
11 1	46 1
5 1	70 7
3.8	78.2

Daviess (1) found that plowing a clover sod with 25.4 per cent moisture gave an average draft of 4.6 pounds per square inch of furrow slice. Similar land after drying down to 19.5 per cent moisture gave an average draft of 5.9 pounds. In this one trial a decrease of 5.9 per cent in moisture increased the draft 28 per cent. Measurements at higher or lower moisture contents were not made.

Ocock (6) made draft measurements on a soil when it was extremely dry, when it was extremely wet, and later when it was in good plowing condition. His results indicate that the plow pulled hardest in the very dry soil and lightest in the soil in good plow condition. The results from the extremely wet soil were slightly higher than for the soil with proper moisture conditions. He made no comparisons of the draft within the range of moisture content that might be considered satisfactory for good plowing.

The results given in this paper differ from Ocock's determinations in that all the measurements were made under at least fairly satisfactory plowing conditions.

Haines (2) reports results of dynamometer tests from the Rothamsted Station on the Barn Field permanent Mangold plots. On one plot the moisture was 28 per cent and the plowing draft was 40 per cent greater than on the immediately adjacent plot with 22 per cent moisture. This was explained on the basis of laboratory tests by the fact that at 28 per cent moisture the soil had reached a peculiar sticky stage corresponding with maximum friction. Neither the treatments of the two plots nor the causes for the difference in moisture contents were given.

In figure 3 comparisons are made between the moisture contents of the soil and the draft both on the unmanured and on the manured plots. The plots have been arranged in the order of increasing draft, including all tests made on each plot. It will be noted that there is a decided general tendency for the moisture curve to fall as the draft curve rises. There are, however, many individual variations. It must be remembered that these curves are based upon results obtained from plots having widely different cropping systems and that they cover tests made at different times from 1923 to 1925. Because of the differences in compactness at these various times the moisture

curves cannot be expected to show as regular correlation as if the tests all could be made at about the same time, but with varying degrees of moisture.

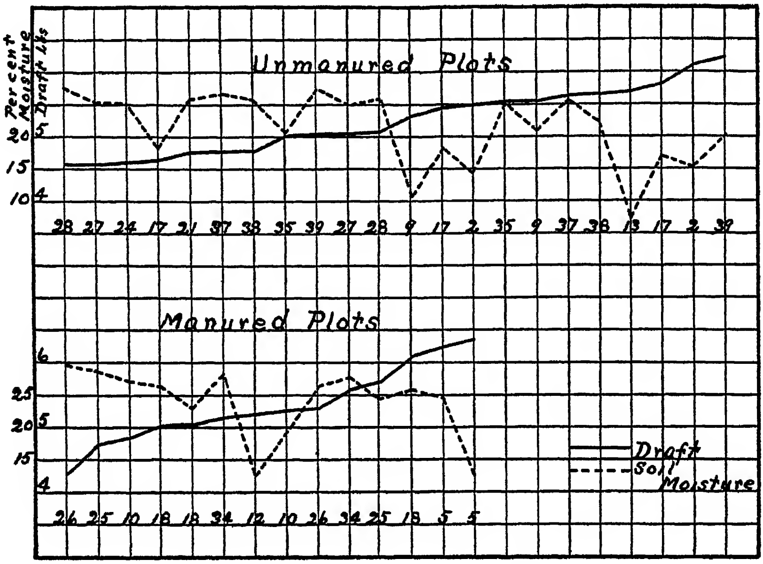

FIG. 3. RELATION BETWEEN SOIL MOISTURE AND THE DRAFT OF PLOWS ON MANURED AND ON UNMANURED LAND

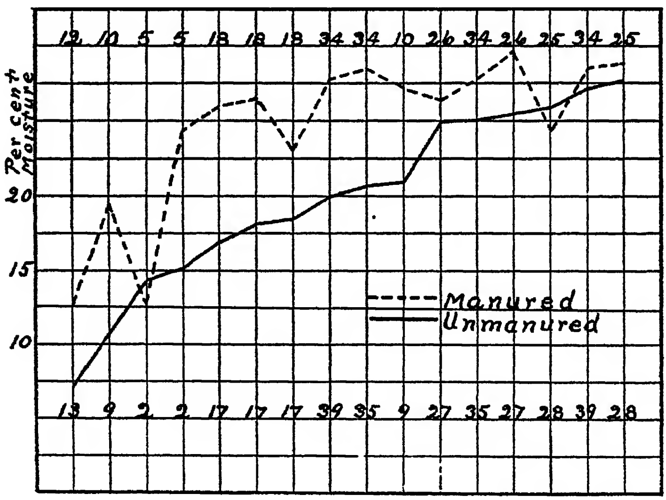

FIG. 4. RELATIVE MOISTURE CONTENTS OF MANURED AND OF UNMANURED PLOTS AT THE VARIOUS SAMPLINGS

EFFECT OF MANURE UPON SOIL MOISTURE

It has long been observed that the water-holding capacity of a soil is increased by applications of organic manures. This fact is brought out in

figure 4 in a comparison of the moisture contents of the manured and unmanured plots at the time of making the dynamometer tests.

Figure 1 shows that on the average and in the greater number of cases, the draft was slightly higher on the manured plots than on the unmanured ones. Figure 3 also shows that the draft tended to decrease as the moisture content of the soil increased. It would seem, if these relations hold true on the average, that if manured land were brought to the same moisture content as the unmanured land the difference in draft would be even greater than is indicated in these tests; that is, the higher moisture content of the manured plots has had a tendency to reduce the draft, but it still remains higher than on the untreated plots.

A comparison of the results from plot 27, untreated, and plot 28 with manure the first 25 years, shows that the draft on April 8, 1925, was practically the same, but that plot 28 had 2.15 per cent more moisture than plot 27. On May 6, plot 28 had a moisture content of 25.8 per cent, or only 0.4 per cent higher than the moisture in plot 27 on April 8. The draft, however, had increased from 4.56 to 5.06 pounds per square inch of furrow slice. This shows that when the moisture content of the manured land was brought down to approximately that of the unmanured, the draft was materially higher. Similar results are shown by a comparison of plots 25 and 26 with plot 27.

From these results it seems likely that if the moisture factor could be eliminated, manured land might be decidedly harder to plow than unmanured land, at least on this particular soil.

SUMMARY

1. Dynamometer tests were made on 19 different plots that had received different rotation and manurial treatments during the past 36 years.

2. The type of soil is Putnam silt loam, but it is somewhat darker and the surface soil is slightly deeper than typical areas of this prairie type.

3. Heavy manuring has had little effect upon the draft of plows, but in general seems to have had a tendency to increase it.

4. The unmanured plots usually work down into a more friable seedbed condition than do the manured plots.

5. Chemical fertilizers, even with rather heavy applications, have not increased the plow draft and, from the limited number of tests, seem to give slightly lower results than manured land.

6. The draft tended to increase as the soil moisture decreased, where the measurements were made under fairly satisfactory plowing conditions.

7. The manured land contained more soil moisture than unmanured land. This fact may have brought the results from the manured and unmanured plots nearer together than if these plots could have been plowed at the same moisture content.

8. It should be understood in this connection that the crop yields from the manured plots have been much higher than from the unmanured land.

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ION EXCHANGE IN RELATION TO SOIL ACIDITY[1]

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The extensive studies that have been made on base exchange by workers in various countries have contributed to a better understanding of soil acidity. As is well known, a neutral soil when treated with a neutral salt solution, such as KCl, loses a part of its bases (chiefly Ca) and gains an equivalent amount of base from the solution. Dilute acids react with soils in a similar way. If a neutral, carbonate-free soil is treated with a dilute acid, the complex with which salts exchange their bases is attacked, and if the acid is sufficiently dilute the reaction is limited to a substitution of H ions for soil bases (5). Ramann (18) and others have aptly designated acid soils as being unsaturated with respect to base.

A detailed review of the voluminous literature on ion exchange in soils seems unnecessary at this time. Numerous papers have been published on various phases of the subject by prominent workers in Germany, Holland, Russia, England and Japan. After the principal part of the experimental work which is presented herein had been completed, the attention of the authors was called to a very interesting discussion by van der Spek published in the Dutch language (22). In his paper[2] Dr. van der Spek has presented considerable experimental data which, when considered in conjunction with the investigations of Hissink (11), Kappen (14), Ramann (18), Daikuhara (7) and others, have led the author to conclusions quite similar to those drawn independently by Gedroiz (9, 10) and which are in close agreement with the views recently published by Hissink (12), Page and Williams (17), and Robinson and Williams (19) and with those presented in this paper.

As shown by Gedroiz (9) and Hissink (11), ion exchange in soils is subject to the principles of mass action and chemical equilibrium, but the several cations differ considerably in their replacing activity. The available evidence is that the replacing activities of these ions stand in the order H > Ca > Mg > K = NH_4 > Na, H ions being much more active than any of the bases named. As bearing on this point the authors have found that upon treating a neutral soil with an acid solution of N NaCl (pH 4.0) the cation exchange was effected mainly by H ions and not by Na ions, notwithstanding the great preponderance of Na over H ions in the solution.

The exchange of H ions for soil bases may be effected to a considerable extent by leaching the soil with a solution low in H-ion concentration, such as an aqueous solution of CO_2. We have found for instance that the exchangeable

[1] Paper No. 137, University of California, Graduate School of Tropical Agriculture and Citrus Experiment Station, Riverside, California.

[2] Acknowledgement is due Dr. Richard Bradfield for the loan of an English translation of this paper. The translation was made by Mr. R. V. Allison of New Jersey.

Ca of a sample of neutral Ramona clay loam was reduced from 0.436 per cent to 0.384 per cent by brief extraction with distilled water saturated with CO_2, and to 0.391 per cent by similar extraction with 0.008 N acetic acid. The carbonic acid dissolved 0.051 per cent Ca and the acetic acid dissolved 0.042 per cent, which was approximately equal in each case to the observed reduction in the exchangeable Ca. The acidity of the soil as determined by the hydrogen electrode was increased from pH 6.95 to approximately pH 5.0. A second extraction with carbonic acid of the first sample dissolved 0.024 per cent Ca, a third, 0.013 per cent; and a fourth, 0.012 per cent, making a total of 0.1 per cent Ca removed by the four extractions. After the fourth extraction with carbonic acid the soil was found to contain only 0.342 per cent replaceable Ca, which indicates that the acid continued to react chiefly with the exchange complex. However, still stronger acids, such as dilute HCl (0.01 N to 0.02 N) may also attack constituents other than the exchange complex, as was shown previously (15).

There is little room for doubt that the acids formed in natural soils by biological processes ultimately bring about a substitution of H ions for soil bases with the formation of simple salts of these bases. Under equilibrium conditions the exchange can not become complete unless a strongly acidic solution is used, but when the equilibrium is disturbed by leaching or as a result of absorption by growing plants, the exchange of H ions for soil bases may finally approach completion.

THE REVERSIBILITY OF ION EXCHANGE IN SOILS

The exchange reaction is at least partially reversible, that is, H ions may be displaced from the exchange complex by the base of a neutral salt solution. The usefulness of the Hopkins method and other similar ones for the determination of soil acidity depends upon this fact. Cummins and Kelley (6) pointed out in 1923 that an acid soil may be converted into an alkaline soil by treatment first with NaCl and then with distilled water. The authors have made a further study of this point, using several types of acid soils drawn from various parts of America.

Twenty-five grams of soil was first digested over night at 70°C. with 250 cc. of neutral N NaCl or $CaCl_2$. The following morning the samples were transferred to a filter and washed at room temperature with fresh portions of the solutions until the leachates came through approximately neutral. The occluded soluble salts were then removed by leaching with distilled water. The pH values of the soil before and after the treatment are shown in table 1. It will be noted that this treatment brought about a material reduction in the H-ion concentration of every soil studied. However, since (*a*) H ions have a greater affinity for the exchange complex than have metallic ions and (*b*) certain organic acids, the base of whose salts is replaceable, appear to be not readily convertible into salts by treatment with a neutral salt of Ca or Na, it may not be possible to displace all of the H ions by this kind of treatment.

As bearing on this point, a part of the replaceable bases of a neutral soil was first substituted by H ions by treating the soil with a dilute solution of acetic acid, and then an attempt was made to reverse the process by leaching the soil at room temperature with N $CaCl_2$. The experiment was only partially successful. The treatment with $CaCl_2$ reduced the H-ion concentration of the acid-treated soil from pH 4.26 to pH 5.42. After the treatment with acetic acid the soil contained a total quantity of replaceable bases equivalent to 0.414 per cent Ca and the final treatment with $CaCl_2$ raised this figure to only 0.455 per cent, instead of to 0.546 per cent, the total amount of replaceable bases expressed as Ca originally present in this soil.

Hissink (12) has obtained similar results. In discussing this point he presents the matter very clearly as follows:

> When we treat a soil with a solution of potassium chloride the filtrate contains H ions. The following reaction takes place;
>
> Soil H′ (solid phases) + K′ + Cl′ (solution) ⇄ Soil K′ (solid phase) + H′ + Cl′ (solution).
>
> Thus there is not only an exchange of Ca, Mg and Na ions of the soil for K ions from the KCl solution, but also an exchange of H ions of the soil for K ions from the KCl solution. It should be noted that the solid phase, the soil, becomes less unsaturated, that is less acid, through this process.
>
> We find, however, that only a part of these H ions is exchangeable. I have for instance leached out a soil (pH 4.5) with a KCl solution up to 2 liters as a result of which the pH of the soil rose to about 5.

On the other hand, Gedroiz (10) seems to think that by leaching the soil with a solution of a neutral salt of high replacing activity, such as $BaCl_2$, the replacement of H ions by Ba may be taken to completion.

By referring to table 1, it will be seen that the leaching with the salt solutions produced a greater reduction in the H-ion concentration of certain acid soils than of others. It seems probable from the evidence at hand, either that soils contain a series of compounds, variable from soil to soil, some of which undergo ion exchange more readily than others, particularly as regards the H ion, or else that the exchangeable ion may occupy more than one position in the molecule of the reacting substance.

The alkalinity developed by treating certain of these soils with NaCl was due to hydrolysis of the Na complexes formed as a result of the substitution of Na for other cations (Ca and H, chiefly the former), and should not be interpreted to mean that all the H was displaced from the exchange complex by Na. In support of this statement Samuels[3] has found in his studies on alkali soils that when Na is the chief replaceable base present the soil may remain alkaline after H ions have displaced a considerable part of the replaceable Na. It appears that the pronounced hydrolytic tendency of the Na complex is responsible for this fact.

The foregoing results help to explain the fact that the application of $NaNO_3$ as

[3] Unpublished thesis.

a fertilizer tends to reduce the acidity of acid soils and if continued may ultimately make the soil alkaline. Moreover, the increased acidity that has been reported from the protracted use of $(NH_4)_2SO_4$ is also readily explained. When this latter salt is applied Ca is at first displaced by NH_4 with the resulting formation of $CaSO_4$. The intervention of nitrification leads to the conversion of NH_4 into HNO_3 with the resulting introduction of H ions into the exchange complex and a consequent increase in the acidity of the soil.

THE DIALYSIS OF SOILS

A neutral soil may be made acidic by merely subjecting it to the process of dialysis, and the change from neutrality to acidity may be hastened by conducting the dialysis under the influence of an electric current. As a means of studying this phase of the subject, an ordinary battery cell, such as is used in

TABLE 1

H-ion concentration of soils as affected by leaching with normal $CaCl_2$ or NaCl followed by leaching with water

SOIL TYPE	LOCATION	pH VALUES		
		Original soil	After treatment with $CaCl_2$	After treatment with NaCl
Clermont silt loam	Indiana	5.14	6.65	7.17
Melbourne clay loam	Oregon	4.99	5.47	6.49
Greenville clay loam	South Carolina	4.80	6.06	6.49
Volusia silt loam	New York	5.22	5.50	7.84
Greenville sandy loam	Alabama	5.10	6.00	
Holston silt loam	Alabama	4.97	6.00	
Rhonerville clay loam	California	5.05	6.51	
Tidal marsh (surface)	California	5.73	6.40	7.81
Tidal marsh (subsoil)	California	4.76	5.51	7.04

automobiles, was separated into three compartments by means of parchment paper held in place by soft rubber.[4] A 25-gm. sample of soil was placed in the central compartment of the cell and all of the compartments were filled to the same level with distilled water. Platinum electrodes connected with a 60- to 65-volt direct current were dipped beneath the surface of the water in the two outer compartments.

The distilled water that was placed in the cathode compartment soon became alkaline whereas that in the anode compartment became slightly acidic. Analysis showed that the alkalinity of the former was due to the hydroxides of bases (chiefly Ca) which dialyzed out of the soil, whereas the acidity noted was due to phosphoric acid, but the amount was always small in comparison with the amount of base found in the cathode compartment.

[4] The authors wish to acknowledge in this connection the helpful suggestions of Dr. S. E. Mattson of the Bureau of Soils. The apparatus used was patterned after that which he has employed in the study of soil colloids.

After having been subjected to the conditions of electro-dialysis for a period of 5 days the soil, whose original pH was 6.95, had become decidedly acidic (pH 4.50). A determination of the replaceable bases showed that the exchangeable Ca had been reduced by the dialysis from 0.436 per cent to 0.280 per cent.

Neglecting the various constituents that are not involved in ion exchange, the following seems a reasonable explanation of the foregoing results: In the presence of water the exchange complex (Ca_xR) ionizes to a slight extent, giving rise to a relatively low concentration of cations (chiefly Ca^{++}) and complex alumino-silicate particles bearing a negative charge. Although a given particle may possibly contain many atoms of exchangeable base, the particle will bear a negative charge whenever the slightest ionization takes place; it will then become essentially a complex anion.

The cation dissociation product of the exchange compounds (Ca^{++}) was able to pass through the parchment membrane and therefore migrated under the influence of the electric current toward the negative pole. H ions, formed by the dissociation of water, also migrated in the same direction. Upon reaching the negative pole the latter were discharged and converted into H_2. The anion, that is, the exchange complex bearing a negative charge, was too large to pass through the membrane. The OH ions of water served, however, to complete the circuit, and upon reaching the positive pole were discharged with the liberation of O_2 and the formation of water. The result was that $Ca(OH)_2$ accumulated in the cathode compartment and the exchange complex remained in the central compartment where it combined with H ions of water and consequently became acidic (base unsaturated). The electric current, therefore, brought about a separation of the products of ionization and thus promoted the ionization process. It merely effected a transfer of ions that were present in the system.

Since, as will be more fully discussed later, the rate at which base is removed from a given soil by dialysis, and probably the rate of cataphoresis of the soil particles also, depend upon the nature of the specific ions present in replaceable form, it appears probable that the degree of ionization of the exchange complex is different depending upon the base with which it is combined.

When H ions are substituted for metallic ions, one of the ionization products of the exchange complex is the H ion. If an aqueous suspension of a partially unsaturated soil is placed in an electric field, H ions together with other diffusible cations that are present will migrate toward the negative pole, but the necessary discharge of the soil complex bearing the negative charge demands that H ions must again be taken up from the solution. Thus the exchange complex, only partially saturated with base and therefore acidic at the outset, will become still more so as the dialysis proceeds.

It seems probable that the process involved in the electro-dialysis of a soil is similar in principle to that which obtains in the region of plant roots where bases are being actively absorbed. In the latter case the valency of the

exchange complex remains saturated through the taking up of H ions from the soil solution. The H ions, being formed by CO_2 excretion and by microbiological activity, replace the bases, and the absorption of the bases by plant roots disturbs the equilibrium by taking up one of the products of the exchange reactions. The result is that in the course of time the soil becomes acidic.

As has been shown by various workers in the field of colloid chemistry, ions condensed on the surface of colloidal materials may be displaced by other ions of like charge. In accordance with the view of a certain school of colloid workers it has long been customary in agricultural literature to explain the phenomena of soil acidity and base exchange on the basis of adsorption. On the other hand, the chemical substitution of one base for another, or of H for base, in the natural silicates appears to be an established geological and mineralogical fact. So far as we are aware every critical study that has been made on the various reactions with soil materials has yielded results that are harmonizable with accepted chemical principles. For example, it has often been reported that different alkalies do not combine with acid soils in chemically equivalent quantities, but Truog (21) pointed out several years ago that, if the determination is so made as to avoid side reactions, the law of combining weights really applies to this reaction. More recently Bradfield (1) in connection with his interesting work on soil colloids has shown that when the experimental conditions demanded by the principles of physical chemistry are maintained the neutralization of the colloid by means of different alkalies follows accepted chemical principles. As is pointed out by Bradfield the results are in harmony with the view that the acidity is due to true acid compounds of low solubility and low ionization. Unpublished data obtained in this laboratory have further strengthened the chemical interpretation of ion exchange in soils.

The aforementioned and various other experiments suggest that ion exchange in soils involves true chemical compounds. The active substances are probably colloidal and therefore the reactions take place largely at the interfaces between the particles and the solution, but this does not prevent its being chemical. It is true that electro-magnetic forces may possibly bring about an orientation of ions and molecules at the interface between a solid and a solution somewhat different from that which obtains in other parts of the solution and which may affect the electro-kinetic properties of the particles. However, as Truog (21) has pointed out, the reactions with the exchange constituents of soils appear to be strictly chemical. The so-called adsorption compounds of soils are probably true chemical compounds.

Hissink (12) recently stated:

> The opinion has of late been gaining more and more ground that the cause of the adsorption is to be sought in chemical attraction; in other words a chemical compound is formed by the adsorbed bases and the particles of the soil. These soil particles can only be the acids in the clay and in the humus, briefly the clay acids and the humus acids. With regard to the composition of these hypothetical clay acids we can only say that they must be a kind of alumino-silicic acid; the humus acids are of course organic acids.

In a recent discussion of the literature Drummond and Page (8) state:

> Now that Bradfield (2, 3) has clearly demonstrated that the colloidal clay material of soils does actually behave as a true acid, this fact together with the proof that the humic acids of soils are also true acids provides a sound experimental basis for Hissink's hypothesis and it is possible to explain all the phenomena in question as chemical ionic reactions of weak acids (clay acids and humic acids), these reactions being localized at a solid-liquid interface owing to the fact that these acids are insoluble and present in the soil as colloidal particles or as gel on the surface of mineral soil particles

Robinson and Williams (19) have expressed a similar opinion.

The existing experimental data seem to agree with the assumption that the inorganic exchange complex is composed of a complex salt of one and probably more of the polybasic alumino-silicic or silicic acids.[5] When the bases have been substituted by H ions the compounds become acid silicates. The soil then manifests acid properties.

THE RELATION OF TRIVALENT BASES TO ION EXCHANGE

When an acid soil is treated with a neutral salt solution, such as KCl or NH_4Cl, more or less Al, Fe and Mn usually pass into the solution. We have shown (15) that the sum of all the bases which are displaced from the soil, including the trivalent metals, may be approximately equivalent to the amount of base which is absorbed from the salt solution. Various investigators (7, 14, 16) have found that the titratable acidity of an extract, obtained by treating an acid soil with a neutral salt solution, is approximately equal to the Al content of the extract. These facts suggest that acid soils may contain trivalent bases in replaceable form. The following experiments were made in the hope of throwing some light on this point.

Different portions of a neutral soil were leached first with solutions of $AlCl_3$ of various strengths and then with distilled water until free from Cl. The chief base removed from the soil by this treatment was Ca and the amount removed increased with the concentration of the $AlCl_3$ solution. The pH of the soil was then determined with the hydrogen electrode and the replaceable bases were determined by the use of a neutral solution of N NH_4Cl.

The results recorded in table 2 show: (*a*) that the preliminary treatment with $AlCl_3$ made the soil distinctly acid, and (*b*) that as the strength of $AlCl_3$ was increased the content of bases (chiefly Ca) originally present in replaceable form suffered progressive diminution. The data suggest, however, that the bases were replaced not by Al ions but by H ions formed as a result of the hydrolysis of $AlCl_3$. It will be noted, for instance, that the amount of NH_4

[5] As pointed out by Gedroiz (9), Hissink (11), and others soils usually contain more or less of organic substances (humic bodies), as well as inorganic substances, which take part in ion exchange. With highly organic soils, such as peaty soils, the chief part of the exchange is probably borne by organic bodies. The soils with which we have worked, however, contain very small amounts of organic matter.

absorbed from the NH_4Cl solution, which is an accurate measure of cations displaced by NH_4Cl, was always in stoichiometric excess of the sum of the displaced monovalent and divalent bases, this being especially pronounced when the higher concentrations of $AlCl_3$ were used. Moreover the NH_4 absorbed was not stoichiometric with the bases dissolved even assuming that the Al found in certain cases was really brought into solution by exchange. As a matter of fact the treatment with concentrations of $AlCl_3$ ranging from 0.001 N to 0.01 N brought about a progressive increase in the acidity of the soil and a corresponding diminution in the replaceable bases without the soil having acquired any substantial amount of replaceable Al.

Since solutions of $AlCl_3$ hydrolyze into HCl and $Al(OH)_3$, the former being highly ionized and the latter only slightly so, the concentration of H ions in the dilute solutions of $AlCl_3$ must have exceeded that of Al ions. The soil bases were displaced by the H ions just as if the soil had been treated with a pure acid of low ionization. At the same time more or less Al was absorbed

TABLE 2

Effects of extraction with NH_4Cl after first treating the soil with $AlCl_3$

NORMALITY OF $AlCl_3$	pH OF SOIL AFTER $AlCl_3$ TREATMENT	BASES EXTRACTED (PER CENT OF SOIL)			MILLIGRAM EQUIVALENTS	
		Ca	Mg	Al	Bases replaced exclusive of Al	NH_4 absorbed
0	6.95	0.436	0.073	0	27.9	27.3
N/1000	5.96	0.359	0.065	0	23.3	27.2
N/500	5.65	0.338	0.046	0	20.7	27.2
N/250	5.05	0.301	0.048	0	19.0	26.1
N/100	4 94	0.202	0.033	Trace	12.8	26.5
N/50	4.84	0.089	0 021	0.117	6 2	25.1
N/10	4.84	0.036	0.013	0.197	2.9	20.7

by the soil as was indicated by the diminished Al content of the solutions used in treating the soil. This absorption, however, was probably effected through the mutual colloidal precipitation of $Al(OH)_3$ and soil colloids rather than by an exchange of Al ions for soil bases, contrary to the conclusion drawn by Gedroiz (9) from similar experiments on the basis of a determination of the Al content of the soil before and after it was treated with a solution of $AlCl_3$.

The absorption of NH_4 in excess of that required to displace the Ca and Mg, referred to above, was probably due to the exchange of NH_4 ions for H ions in the exchange complex.

It will be noted that the preliminary treatment with the more dilute solutions of $AlCl_3$ brought about an inverse proportionality between the acidity of the soil and its total content of replaceable base, but that this inverse relationship disappeared after approximately one-half of the replaceable bases had been substituted by H ions. In connection with electro-dialysis experiments it was found that upon bringing about approximately complete substitution of H ions for the bases of this soil the acidity finally reached pH 4.0,

which appears to be the maximum acidity attainable by the ionization of the alumino-silicic and organic acids of this soil.

The existing evidence indicates, as pointed out by Saint (20), that it is the solvent power of the salt solution, enhanced by displacement of H ions from the exchange complex, that is chiefly responsible for the solution of the trivalent bases upon treating an acid soil with a neutral salt solution. It is also indicated that in some cases the soil solution itself may become sufficiently acid to dissolve significant amounts of these bases. In this connection we have found that $Al(OH)_3$, either when absorbed from a solution of $AlCl_3$ or when added to a soil as such, is considerably more soluble in an acid solution of KCl than in an NH_4Cl solution of equal H-ion concentration.

As has been shown by various workers, Al is the principal trivalent base of importance in certain acid soils. In other soils Mn predominates. We have found, for instance, that with a sample of neutral Ramona clay loam the solubility of Mn in N NH_4Cl was increased from a trace to 0.034 per cent by dialyzing out approximately one-third of the replaceable bases, and to 0.066 per cent by dialyzing out approximately two-thirds of the bases. The dialysis produced no change in the solubility of Al and Fe. In addition a sample of Greenville sandy loam, sent from Alabama by Dr. F. W. Parker, contains 0.037 per cent Mn soluble in N NH_4Cl, and a sample of Holston silt loam contains 0.081 per cent, but neither of these acid soils contains appreciable amounts of soluble Al or Fe. On the other hand a sample of colloidal material (pH 5.35) separated by Dr. Bradfield from acid Putnam clay was found to contain 0.145 per cent Al and 0.112 per cent Fe soluble in N NH_4Cl.

Whatever may be the origin of the compounds of the trivalent bases and the mechanism by which they are brought into solution in acid soils, either by salt solutions or by the soil solution, it is clear that soil acidity is a phenomenon which involves a diminution in the supply of replaceable Ca with a corresponding increase in the H content of the exchange complex. Acid soils are, therefore, to be regarded as being in a state of unsaturation with respect to bases.

THE CONTENT OF REPLACEABLE CA IN ACID SOILS

A determination of the replaceable Ca in several acid soils obtained from various parts of America showed a relatively low content of Ca. The results are in agreement with those obtained by Robinson and Williams from a study of Welsh soils (19). The deficiency in the replaceable Ca becomes especially apparent when the data (table 3) are compared with those previously reported for approximately neutral soils both in America (15) and in Europe (9, 11, 17).

It does not follow, however, that an acid soil *necessarily* contains a low absolute amount of replaceable Ca, for the substitution of H ions for only a comparatively small part of the replaceable Ca may produce an acid reaction, as was shown earlier in this paper. Neither does it follow that the exchangeable H-ion content is necessarily high in an acid soil whose replaceable Ca is low, since the total content of exchangeable cations, as well as that of Ca, may

be low. These statements are strongly supported by unpublished data obtained in the course of studies on the colloidal materials which were separated from different soils by the use of the super-centrifuge.

GENERAL DISCUSSION

At least three general principles must be considered in arriving at an understanding of soil reaction; namely, (*a*) direct ionization, (*b*) hydrolysis, (*c*) the so-called buffer effect.

As is shown by the foregoing experiments on dialysis, the exchange complex ionizes to some extent. If Ca is the only cation component of this complex, the compounds are reasonably stable chemically and practically non-hydrolizable and, therefore, give an approximately neutral ionization. When H ions enter, the compound tends to give an acid ionization, but there is some doubt as to whether the soil with a small part of the exchangeable base substituted by H ions is necessarily acidic. Gedroiz (9, 10) has suggested, for example, that, although $CaCO_3$ serves to protect the exchange complex against attack it is possible that the substitution of H ions of biological origin for bases may begin before the last traces of $CaCO_3$ have been decomposed. If this is true it means that the base-unsaturated complex can exist in equilibrium with $CaCO_3$.

TABLE 3

Replaceable Ca content of various acid soils

TYPE	LOCATION	pH	Ca
			per cent
Clermont silt loam	Indiana	5.14	0.068
Unclassified clay loam	California	4.97	0.027
Rhonerville clay loam	California	5.05	0.053
Hagerstown clay loam	Pennsylvania	4.77	0.021
Melbourne clay loam	Oregon	4.99	0.037
Greenville clay loam	South Carolina	4.80	0.060
Volusia silt loam	New York	5.22	0.103
Cecil clay loam	Georgia	6.12	0.018
Tidal marsh clay loam	California	5.73	0.112
Tidal marsh subsoil	California	4.76	0.088
Greenville sandy loam	Alabama	5.10	0.041
Holston silt loam	Alabama	4.97	0.056
Miami loam	Michigan	6.59	0.219
Glaucester silt loam	Wisconsin	5.90	0.169

It seems possible as suggested by Page and Williams (17) that:

> As weak acids these complex acids will exist entirely in the form of salts (i.e. the soil will be saturated in the modern sense) only when the solution is quite alkaline, with a pH far above 7, whereas in a neutral or faintly alkaline soil, with a pH of 7 to 8, in equilibrium with calcium carbonate, which in Ramann's terminology would be termed an absorptively saturated soil, the degree of saturation in the modern sense would still be far from complete; that is an appreciable proportion of the complex acids would still exist in the free state, or the

absorbing complex would still contain exchangeable hydrogen ions which could be liberated by base exchange with a neutral salt.

If this view is sound, it follows that the mere application of an excess of $CaCO_3$ will not change an acid soil into a state of base saturation (17, p. 583). The application of $CaCO_3$ would, of course, modify the reaction of the soil and improve its crop-producing power, as experience has abundantly proved. Hissink (12) recently published data which indicate that an acid reaction may not ensue until a relatively large percentage of the base of a saturated soil has been substituted by H ions.

We expect to discuss this point more fully in a separate paper to be devoted to a consideration of analytical methods for the determination of replaceable H ions. At present it will suffice to say that our results indicate that, so far as the exchange complex of normal soils is concerned, an acid reaction ensues whenever any considerable part of the replaceable base is substituted by H ions. It should be borne in mind, however, that the exchange silicates, like the phosphates, may ionize in various ways. The ionization might be represented by either of the following:

$$HR \rightleftarrows H^+ + \overline{R},$$

$$Ca_xHR \rightleftarrows H^+ + Ca_x\overline{R} \qquad \text{or}$$

$$Ca_xHR \rightleftarrows Ca^{++} + Ca_{(x-1)}\overline{\overline{HR}}.$$

If the last predominates the reaction would probably be approximately neutral.

Hydrolysis may involve both the exchange complex and the various crystalline minerals of soils. When Na comprises any considerable part of the total replaceable bases, the complex, as already pointed out, tends to undergo hydrolysis with the resulting formation of small amounts of NaOH.[6] The crystalline silicates, as well as $CaCO_3$, may also undergo hydrolysis. As is well known, various silicates, such as the feldspars, yield alkaline solutions by hydrolysis. The hydrolytic products of these silicates may possibly dominate the reaction of a carbonate-free soil whose exchange complex is slightly unsaturated with bases.

The buffer effect of soils, as commonly understood, is concerned mainly with the exchange complex and is an expression of the replacing activity of H ions. As is indicated above, H ions are energetic replacing ions. When the H-ion concentration of a solution brought into contact with a given soil exceeds that given by the ionization of the exchange complex, an exchange of ions will take place with the result that H ions will be absorbed from the solution and a simple salt of the substituted base will be formed. The buffer property against acids is thus conditioned on the presence of base in replaceable form and its extent is determined by the amount present.

[6] This hydrolysis, as suggested by Gedroiz (10) and by Joffe and McLean (13), may, of course, be regarded as merely an aspect of ion exchange in that H ions of water displace Na from the soil. It is doubtful, however, whether anything is gained by this view.

From the foregoing discussion it must be apparent that the H-ion concentration of a soil is not necessarily correlated with the composition of the soil solution. On the other hand the composition of this solution, its constancy, and its rate of renewal vitally affect the crop-producing power of the soil. Reasoning from general principles one must assume that the composition of the soil solution is profoundly influenced by biological action and that the bases required by plants are brought into solution largely by biologically formed acids. Recent investigations by Burd (4) strongly support this view. Since in the absence of carbonates these acids tend to react, as already shown, by the substitution of H ions for Ca, a soil which is free from $CaCO_3$ and low in replaceable Ca must be regarded as being essentially deficient in Ca. Acids formed in such a soil by biological action tend to bring into solution toxic concentrations of Al or Mn.

From this point of view the unproductivity of acid soils and the beneficial effects of liming become intelligible. As pointed out by Robinson and Williams (19) the unproductivity is not necessarily due to the H-ion concentration directly; toxic concentrations of Al or Mn and insufficiency of phosphate supply may be involved, and perhaps equally important may be the inadequacy of the available Ca supply. The application of lime tends to reduce the H-ion concentration, lower the solubility of Al, and furnish an available supply of Ca. In consequence of all these changes together with the indirect effect on the solubility of phosphates and on micro-biological processes, crop growth is promoted.

These studies also afford an explanation of the well-known fact that, whereas the application of $CaCO_3$ may improve the crop-producing power of an acid soil, the application of gypsum may not do so. The latter would undoubtedly tend to overcome the deficiency in available Ca but this advantage might be more than offset by the replacement of H ions with the consequent increase in the acidity of the soil solution and the resultant dissolving of toxic Al.

SUMMARY

1. Dilute acids react with soils in much the same way as neutral salts. The reaction involves an exchange of ions. When reacted upon by acids the exchange complex gives up base in exchange for H ions. The soil then becomes unsaturated with base and therefore acidic. The condition of unsaturation with respect to base is characteristic of acid soils. This condition is brought about in natural soils by the combined effect of biologically formed acids, leaching and the absorption of bases by growing plants.

2. H ions are energetic replacing ions. Weak acids, such as carbonic acid, are capable of effecting an exchange of H ions for soil bases. The H ions may in turn be displaced from the soil, in part at least, by the base of a neutral salt, with the resulting formation of an acid solution.

3. The exchange complex ionizes to some extent, as dialysis experiments indicate. The ionization products of a base-saturated soil are composed

largely of the replaceable bases as cations and the alumino-silicate particles as anions. When the dialysis is conducted under the influence of an electric current, the bases accumulate around the cathode and can be separated from the soil and determined as the hydroxides. At the same time the exchange complex becomes acidic through the taking up of H ions from the solution. It is possible to effect approximately complete substitution of H ions for the replaceable bases by this means.

4. The replaceable bases of mineral soils are believed to be chemically combined as salts of one or more of the alumino-silicic acids, and when substituted by H ions the compounds become acid silicates. It is suggested that the electro-negative character of soils, their cataphoretic property, etc., are due in part at least to the ionization of true chemical compounds, rather than to the influence of adsorbed ions.

5. When a soil is treated with $AlCl_3$ a replacement of soil bases takes place. The H ion, formed as a result of hydrolysis, and not the Al ion, is responsible for the resplacement. The trivalent bases which are removed from an acid soil by extraction with a neutral salt solution are probably brought into solution as a result of the solvent power of the solution, which power is materially increased by the H ions that are displaced from the exchange complex by the neutral salt.

6. A considerable number of acid soils were found to contain subnormal amounts of replaceable Ca. It seems probable that this condition will prove to be a general characteristic of acid soils.

7. The H-ion concentration of a soil is determined by: (*a*) the dissociation products of the exchange complex which it contains, (*b*) the hydrolytic products of the exchange compounds and various other compounds that may be present, and (*c*) the buffer property of the soil. The last-named factor is determined largely by the total amount and by the specific nature of the several replaceable bases present.

8. The application of lime produces various chemical effects on acid soils. Among the more important are: (*a*) the neutralization of acids with the consequent introduction of Ca into the exchange complex, (*b*) a reduction in the solubility of Al, and (*c*) an increase in available Ca. Acid soils are physiologically deficient in base; their available Ca is likely to be inadequate.

9. An explanation is offered for the fact that the application of $NaNO_3$ tends to reduce the acidity of soils, whereas $(NH_4)_2SO_4$ increases it. The superiority of $CaCO_3$ over $CaSO_4$ as a treatment for acid soils is briefly referred to.

10. The results reported in this paper are in harmony with the conclusions of Truog, Bradfield and several European investigators; namely, that the acidity of mineral soils is due primarily to acid silicates.

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THE EFFECT OF VARYING THE NITROGEN SUPPLY ON THE RATIOS BETWEEN THE TOPS AND ROOTS IN FLAX

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PART 1

In an earlier paper (1) in which the writer reported studies bearing upon the mechanism of the physiological effects of nitrates in altering the ratio of top growth to root growth in seed plants, it was noted that certain plants showed no appreciable change of top-root growth ratios when the nitrate content of the medium in which they were growing was increased. *Flax* was one of the plants which showed very little or no response to the nitrate treatment, whereas certain other plants such as *barley* and *corn* showed unmistakable increments in the ratios as nitrates were increased.

The writer made the following statement about the behavior of *flax* in the aforementioned paper:

> It will be noticed that this plant makes no appreciable response, in the ratio of tops to roots, to increased nitrate content of the solution. In other words, it would seem that in the case of *flax* we are dealing with a plant of a different physiological constitution in so far as its ability to utilize nitrates is concerned. To what range it might respond, the limits of this experiment have not permitted investigation, but this fact presents a very interesting problem from the standpoint of *flax* nutrition.

Further studies have been carried on with *flax*, to the end of throwing some additional light upon the behavior of this plant.[1] The *flax* plants were grown in quart jars in specially devised nutrient solutions, which were described in the former paper. Though the preparation of these solutions may require somewhat more labor than the nutrient solutions which one finds given ordinarily for physiological studies, they furnish a much better method of varying simple anions or cations, and at the same time they avoid the introduction of non-nutrient constituents. Three sets of plants were grown simultaneously in solutions which differed mainly in nitrate content. The pH value of the low nitrate solution was 6.46; of the medium nitrate, 6.81; and of the high nitrate, 6.46. The flax used was a seed type, variety Winona, C.1, no. 179.[2]

These studies were conducted along two lines. The first effort was concerned with growing the plants, noting growth characters, and with harvesting at

[1] These investigations were carried on in the Biological laboratory of Hampton Institute.

[2] The flax was kindly supplied by Mr. A. C. Dillman in charge of seed flax investigations of the United States Department of Agriculture

intervals of one week, beginning in the experiments reported here, 32 days after the cultures were set up. Four cultures were harvested to a series, the tops being carefully separated from the roots and both dried to constant weight, at 100°C.

Table 1 gives the result of an experiment of 45 days duration. It will be seen that for the 32-day period the ratios of tops to roots as shown by their dry weights are 3.34, 3.09 and 3.22 respectively for the low nitrate, medium nitrate, and high nitrate solutions; for the 39-day period the results are not materially changed; and the small change for the 45-day period is not significant

TABLE 1

Ratio of top growth to root growth in flax as nitrate concentration is increased

SOLUTIONS	SERIES 1–32 DAYS			SERIES 2–39 DAYS			SERIES 3–45 DAYS		
	Tops	Roots	Tops/Roots	Tops	Roots	Tops/Roots	Tops	Roots	Tops/Roots
	gm.	*gm.*		*gm.*	*gm.*		*gm.*	*gm.*	
Solution 1. Low nitrate..	0.8957	0.2675	3.340	1.5935	0.5242	3.039	2.5722	0.7488	3.43
Solution 2. Medium nitrate...............	0.6917	0.2237	3.092	1.1169	0.3682	3.034	2.1732	0.5581	3.89
Solution 3. High nitrate.	0.7183	0.2227	3.220	1.0493	0.3233	3.240	1.6464	0.4134	3.98

TABLE 2

Ratios of top growth to root growth in barley and in corn as nitrate concentration is increased

		28 DAYS	35 DAYS	42 DAYS	49 DAYS
Barley.........	Solution 1	4.37	4.94	4.99	5.33
	Solution 2	5.13	6.56	7.71	8.28
	Solution 3	5.75	6.84	7.66	9.08
		27 DAYS	34 DAYS		41 DAYS
Corn..........	Solution 1	4.44	5.71		6.41
	Solution 2	4.87	7.54		9.75

when compared with *barley* or *corn* grown for the same periods, and under similar conditions. Figures have been given (1) which show closer ratios for flax than are reported here.

Table 2 shows markedly increasing ratios with *barley* and *corn*. Several preliminary experiments were carried on with *flax*, all giving practically the same results.

A comparative study of the figures in tables 1 and 2 shows that the smallest quantity of nitrate used in *flax* has the same effect as the largest in stimulating the growth of tops. It would thus seem that the use of nitrates for *flax* culture, except in minimal quantities would be a waste.

PART 2

It was thought that since *barley* and *flax* as types, showed such different behavior in the presence of increased amounts of nitrates, a chemical analysis for the total nitrogen content of the plants grown with the different treatments of nitrates would throw some light upon the relative assimilation of nitrogen by the two. For this purpose, therefore, a second set of experiments was made.

The material preserved from the first set of experiments (tables 1 and 2)

TABLE 3

Percentages of nitrogen in flax and barley compared when grown in nutrient solutions with different quantities of nitrates

	Nitrogen in flax			Nitrogen in barley	
	Tops		Roots	Tops	Roots
		per cent	*per cent*	*per cent*	*per cent*
Solution 1. Low nitrate		3.36	2.68	2.40	
		3 14	2.64	2.44	
		3 30			
		3 30			
	Total	13.10	5.32	4.84	
	Mean	3.275	2.66	2.42	
Solution 2. Medium nitrate		3.70	3.34	4.34	3.80
		3.64	3.40	4.30	4.04
		3.78			
		3.88			
	Total	15.00	6.74	8.64	7.84
	Mean	3.75	3.37	4.32	3.92
Solution 3. High nitrate		3.92	3.58	4.74	4.18
		4.38			
		4 02	3.44	4.78	4.24
		4.44			
	Total	16.76	7.02	9.52	8.42
	Mean	4.19	3.51	4.76	4.21

was now ground finely, in separate lots, and carried through the Kjeldahl process for total nitrogen determinations.

Determinations for the tops of *flax* were run in quadruplicates, whereas all others were in duplicates.

Table 3 gives the results of these experiments. The differences among the percentages of nitrogen found in tops of *flax* grown in the three solutions are small, 3.275 per cent, 3.75 per cent, and 4.19 per cent respectively. In case of *barley* the percentage of nitrogen in tops of the low nitrate cultures—2.42

per cent—was decidedly lower than for the medium—4.32 per cent—and high nitrate—4.76 per cent. The small difference in percentage of total nitrogen found in *flax*, paralleled the ratios of top growth to root growth in this plant, which shows slight and rather irregular differences. This is in contrast to the large difference in percentage of nitrogen found between the low and medium nitrate cultures of *barley*, which showed, also, large differences in the ratio of top growth to root growth.

DISCUSSION

In the case of *barley* and *corn* the increased ratio of tops to roots which results from increasing the amount of nitrogen in the solution seems to be due to the increased use of carbohydrates in the tops, because the greater nitrogen supply allows for greater growth. There is no inhibiting effect of nitrates upon the roots, but as the tops are stimulated to use more of the photosynthetic carbohydrates the roots decrease in number and, therefore, show relatively less growth; the result being a marked increase in ratio of tops to roots. The mechanism seems to be different with *flax*. These and former studies show that in this plant the tops are not able to profit by an increased supply of nitrates beyond a certain low limit. They show further that the smallest amount of nitrates used was as effective in bringing about a change in ratio of top growth to root growth as the largest which was twenty times as much.

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PHYSIOLOGICAL ACTIVITY OF THE SEMINAL AND NODAL ROOTS OF CROP PLANTS

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INTRODUCTION

Plants of the grass family possess two distinct root systems which develop at different periods. The primary or seminal root system develops immediately upon germination and usually consists of several roots, the number of which depends on the species of plant. The young seedling is entirely dependent for its nutrition on this primary or "temporary" root system. Later, during the period of tillering, a second root system, known as "nodal" or "permanent" develops from the lower nodes of the main stem and of the tillers. When the grain is planted shallow, or when it germinates in the light, as for instance in the laboratory, both root systems are closely connected, the nodal roots surrounding the seminal ones, so that these latter can scarcely be noticed. When the grain is planted deep, the nodal roots are obviously separated from the seminal ones by the elongated wiry lowest internode (wheat, barley, rye) or by the mesocotyl (mais, sorghum).

The two root systems exhibit great differences in their morphological and anatomical structures. Detailed descriptions of the structure of both root systems may be found in the works of Jackson (3), Percival (8), Sleskin (16), and O. A. Walther (18, 19). Whereas the primary roots are very slender and branched throughout their length, having a thin walled cortex with no exodermis, the nodal roots are centrally thicker, and possess a wider central stele. Wide difference of opinion exists, however, concerning the functions and life activity of the two root systems. There seems to be full agreement among the investigators in this field (2, 4, 6, 7, 9, 10, 11, 13, 15, 21, 22) that the primary root systems (in most of the plants) function only temporarily, and gradually die off when the nodal root systems develop. The question, however, is far from being settled, especially in plants like corn and sorghum. Miller (5), Schellenberg and Kirchner (4), and Zawodny (23) find that the single seminal root of corn and sorghum functions in the plant during all its life. They even suggest that this life-long function of the primary root system distinguishes this group of crops from the rest of the grass family. Percival (8) admits the possibility of the seminal roots functioning throughout the life of the plant, as they are often found undecayed up to the time of harvest. Jackson (3), studying the root system of barley at different stages of development, states that the seminal roots form the "bulk" of the root system of this plant. Rotmistrov (12)

[1] This study was carried out in the Laboratory of Plant Physiology in the Leningrad Agricultural Institute. The writer is deeply indebted to Prof. O. A. Walther for suggesting the problem and for valuable and helpful criticisms in the course of the work.

has observed that the primary roots continue to be the main part of the root system during the entire period of vegetation, the nodal roots developing only when conditions of moisture and nutrition are favorable. Finally Weaver, Jean, and Crist (20) after numerous investigations on the root systems of these plants agree with Rotmistrov, that the seminal roots remain alive and active up to the time of harvest.

In view of these contradictory opinions it appeared necessary to study the functions of the two root systems experimentally; more so because most of the investigators drew their conclusions from mere observations of the appearance of roots, and not from experimental work.

The purpose of these experiments was, therefore, to study the rôle that each of the two root systems plays in the nutrition of the plant.

Two series of experiments were carried out: In the first, wheat, barley, and rye were grown in the culture solution with the two root systems separated, each being immersed in a different jar; in the second, one of the two root systems was entirely removed from the plant in order to observe how the plants would react to the removal of either of the root systems.

EXPERIMENTS WITH ISOLATED ROOT SYSTEMS

Methods

Seeds of pure line of wheat (*Tr. vulgare lutescens*), summer and winter rye (*Secale cereale*), as well as barley for the second series of experiments (*Hordeum v. pallidum mandschuricum*, no. 69) were obtained from the Station of Applied Botany and Selection in Leningrad. Seeds of bare barley were obtained from the Nikolaewski Experiment Station of the Leningrad Government. They were not of a pure line but produced very uniform seedlings.

The seeds were sown June 1, 1923 on filter paper. After the roots and plumule had appeared, the seedlings were transferred to liter jars containing Knop's solution; at the appearance of the first nodal roots uniform plants were selected and transferred to the double jars, where every five or six days account was taken of the growth of the plants and of the water and salts absorbed. For convenience and in order to place both root systems under similar conditions, flat-sided jars of equal volume (850 cc.) were used. Placed close together they appeared as one single jar with a double partition in the middle. (Plate 1, Fig. 1 to 3.) To give free access to the root system (for the newly developing nodal roots had to be constantly directed with forceps to the compartment of the double jar assigned to them) the plants were inserted in corks slightly above the level of the partition, as shown in figure 1. The corks were fixed between two croosbeams supported by tin plates fastened to the jars and projecting 1 to 2 cm. above the level. In order to protect the jars from evaporation and to exclude light, paraffined cardboard covers were provided and the jars were wrapped in paper. As there was no possibility of obtaining a sufficient supply of distilled water, the cultures were grown in tap

water. As the water contained much calcium, the following solution gave the best results:

1.0 gm. $NaNO_3$	0.12 gm. KCl
0.25 gm. $MgSO_4$	0.012 gm. $FeCl_3$
0.25 gm. KH_2PO_4	1000 cc. tap water

Nitric acid was added to keep the hydrogen-ion concentration at about pH 6.5 to 6.7, and the solution was changed every 5 to 7 days. The experiments were carried out in a cold greenhouse. The amount of water absorbed was determined by adding water to a constant volume. Changes in the concentration of the culture solutions were determined by the Kohlrausch method. The solutions were restored to their original volume before the concentration was determined. The Kohlrausch method allows one to obtain only approximate values in a solution of several salts. If the changes in dissociation caused by the comparatively insignificant dilution of the solution by the plant are neglected, it may be admitted that the amount of salts absorbed is approximately proportional to the change in specific conductivity.

Records were taken from the time of transfer to the double jars to the time of maturation of the main stem. The plants were harvested after 114 to 116 days of growth.

Experimental data

Development of the plants. Before a survey of the root activity is entered upon, it should be noted that the plants tillered profusely. Simultaneously the nodal roots developed more abundantly than in natural field conditions. The plants possessed from 25 to 50 nodal roots, from 11 to 17 stalks, carrying 7 to 12 heads, although according to the data of other authors and experiment stations, summer crops in field conditions yield from 2 to 4 stalks with 1 to 2 heads and possess about 16 nodal roots [Brenchley (1), Weaver (20), and Percival (8)]. On the other hand the seminal roots of the experimental plants were weakly developed, attaining only a length of 30 to 40 cm., although seminal roots of other species in water cultures have been observed to attain over 100 cm. [Walther (18)], confirmation of which in soil cultures may be found in the literature [Weaver (20), Jackson (3), and Schulze (14)]. In surveying the root activity in the following experiments one must have in view this relation to the development of the root systems and tillers.

The data presented in tables 1 to 4 and in figures 1 to 4, were obtained on duplicate plants from each jar. In tables and curves all the data are calculated to the average activity of one plant in one day in the mentioned interval of time. Data are given, in centimeters, of the average daily increase in growth of the main stem and of the average summary increase of all the tillers measured to the tip end of the highest leaf.

Wheat. Three pairs of plants and one singly planted seedling (four double jars in all) contribute data concerning the root activity of wheat, but for the

sake of brevity the results of only two pairs are presented, the remaining two pairs giving approximately the same results.

Table 1 and figures 1 and 2 show that the absorption of water by the seminal roots rises rapidly at first, reaching its maximum at the time of stalking and energetic tillering, then decreases to about one-half of its maximum and then remains constant, fluctuating only under the influence of weather conditions. Nodal roots gradually increase in their activity beginning with the period of tillering, follow the increased growth of the tillers, finally overtaking the seminal roots at the time of stalking when the activity of the seminal roots falls, reach their maximum at the period of energetic heading and flowering of the tillers, then gradually decrease in their activity accompanying the ripening and desiccation of the older leaves.

In table 2 figures are presented of the total amount of water absorbed by each root system separately in three periods of development: (I) from the stage of 3 leaves to the stage of stalking; (II) from the time of stalking to the time of flowering; and (III) from the time of flowering to the mature stage of the main stem. In the last column is calculated the part taken by the seminal roots in the absorption of water, expressed in per cents of the total amount of water absorbed in the given period.

This table clearly demonstrates that even in the last period of development of wheat the work of the seminal roots does not fall below 17 to 28 per cent. Taking into consideration that the plants possessed from 11 to 17 stalks and 7 to 13 heads, we may calculate that the seminal roots for their part supplied 2 or 3 stalks. Under natural field conditions tillering is far weaker, fewer nodal roots being formed, and the less the tillering and root formation the greater is the relative part played by the seminal roots in the nutrition of the plant, as indicated in table 3.

Absorption of salts by the seminal roots continues throughout the vegetation period of wheat and reaches its maximum near the time of stalking and heading when the main stem attains its maximum increase in growth. The salt absorption by the nodal roots reaches its maximum near the time of the maximum increase in growth of the tillers. Such a coincidence in maximum of growth and of absorption seems to indicate that the seminal roots serve principally the main stem, whereas the nodal roots work for the benefit of the tillers. A second rise in the curve of salt absorption by seminal roots of wheat as well as of barley may be explained either by increased requirements of nutrients during flowering of the main stalk, or more probably, by the growth of "parasite" tillers, which developed on higher nodes of the main stalk. As the nodal roots of these tillers could not reach the water, they had to draw their nutrients through the main stem and thereby stimulated the activity of the seminal roots.

That the nodal roots absorbed a more dilute solution than the seminal ones, is shown in columns 11 and 12, table 1.

Barley gave a similar picture of root activity (table 4 and fig. 3 and 4) with the only difference that the seminal roots did not reveal a decrease in water

TABLE 1

Water and salt absorption, growth and development of wheat no. 5

DATE	NUMBER OF DAYS	AVERAGE DAILY ABSORPTION OF WATER: By the seminal roots	By the nodal roots	Total	Nodal root absorption per unit of seminal root absorption	AVERAGE DAILY ABSORPTION OF SALTS: By the seminal roots	By the nodal roots	Total	Nodal root absorption per unit of seminal root absorption	AMOUNT OF WATER ABSORBED PER MILLIGRAM OF SALT: By the seminal roots	By the nodal roots
1	2	3	4	5	6	7	8	9	10	11	12
		cc.	cc.	cc.		mgm.	mgm.	mgm.			
June 23–25	2	2.12	....	2.1	0	..	..	..	....	....	....
June 25–27	2	3.15	....	3.2	0	..	..	..	....	....	....
June 28–30	2	3.80	0.9	4.7	0.24	..	..	..	....	....	....
June 30 to July 3	3	8.66	1.5	10.2	0.17	..	..	..	....	....	....
July 3–8	5	17.65	3.5	21.2	0.19	21	7	28	0.33	0.84	0.49
July 8–11	3	19.16	6.9	26.1	0.35	..	..	..	....	....	....
July 11–13	2	28.00	17.9	45.9	0.63	..	..	..	....	....	....
July 13–18	5	19.60	16.3	35.9	0.83	26	14	4.0	0.52	0.75	1.17
July 18–21	3	8.08	9.4	17.5	1.16	..	..	..	....		
July 21–25	4	10.06	13.0	23.1	1.29	..	..	..	....		
July 25–30	5	11.30	18.4	29.7	1.63	20	24	44	1.20	0.57	0.77
July 30 to August 3	4	4.37	10.8	15.2	2.47	..	..	..	....		
August 3–6	3	6.16	17.2	23.4	2.79	..	..	..	....		
August 6–11	5	9.70	24.2	33.9	2.49	11	26	37	2.30	0.88	0.93
August 11–14	3	6.66	18.2	24.9	2.57	..	..	..	....		
August 14–17	3	9.00	26.8	35.8	2.98	..	..	..	....		
August 17–23	6	9.00	26.8	35.8	2.98	17	30	47	1.7	0.53	0.89
August 23–26	3	11.08	27.2	38.3	2.45	..	..	..	....		
August 26–29	3	12.50	31.7	44.2	2.53	..	..	..	....		
August 29 to September 3	5	9.37	25.2	34.6	2.66	16	31	47	1.9	0.58	0.81
September 3–10	7	5.71	13 5	19.2	2.37	..	..	..	....		
September 10–15	5	8.25	18.9	27.2	2.28	16	20	36	1.3	0.52	0.94
September 15–21	6	12.70	33.0	45.7	2.59	..	..				

DEVELOPMENT AND GROWTH IN HEIGHT: Date	Main stem: Stage of development	Height to the tip end of the leaf	Average daily increase in height	Tillers: Number of tillers	Summary height of all tillers to end of leaf	Daily increase in height	Number of heads
13	14	15	16	17	18	19	20
		cm.	cm.		cm.	cm.	
June 22	3 leaves						
June 28	Tillering	30.75		1.0	9.5		
June 30	4 leaves			1.5	10.0	0.3	
July 3	5 leaves	38.50	1.7	1.5			
July 10		45 00	1.0	3 0	59.5	4.9	
July 15	Stalking	54.00	1.8	3.0	76.0	3.3	
July 20		61.50	1.3	4.5	102.5	5.3	
July 25		66.00	0.9	5.5	132.5	6.0	
	Heading						
August 3	Flowering	67.00	0	8.5	242.5	10.0	1.0
August 11		67.00	0	8.5	329.0	10.9	2.5
August 19				9.0	425.0	12.0	3.5
August 27				9.5	507.0	10.2	6 5
September 6				11.5			
September 21				11.5	603.0	3.8	7.0

absorption after stalking of the main stem. On the whole the seminal roots of barley are slightly more active than those of wheat and play a greater part in the provision of water, supplying from 29 to 31 per cent of the total amount of water absorbed by the plant. This may probably be explained by the healthier growth of barley in its first stages of development when the seminal root system is formed. The wheat at that time was weaker and suffered from chlorosis.

It is interesting to compare the absorption of water by the different root

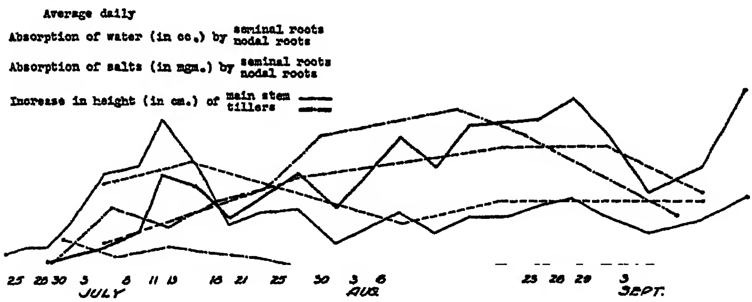

FIG. 1. WATER AND SALT ABSORPTION, AND GROWTH OF WHEAT NO. 5

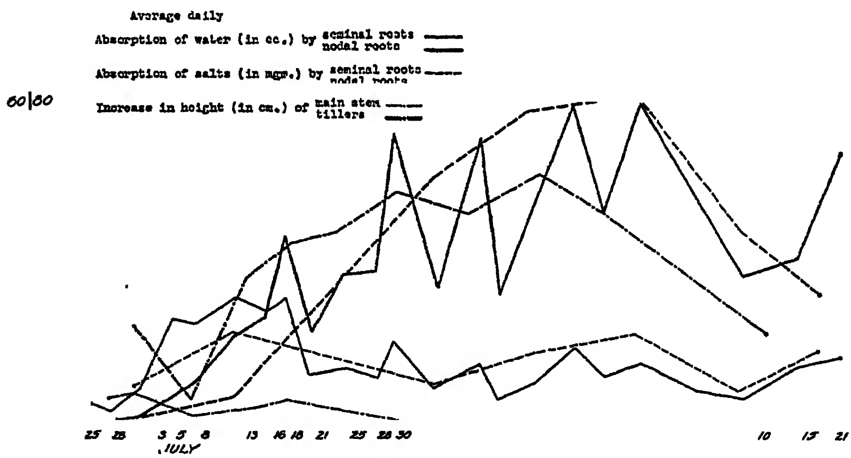

FIG. 2. WATER AND SALT ABSORPTION, AND GROWTH OF WHEAT NO. 6

systems of wheat and barley calculated in relation to 1 gm. of dry weight of the roots. Very often in determinations of root activity in different soil layers, the dry weight of the roots found in these layers serves as a measure. Table 5 shows that the seminal roots in the third period of growth absorb almost double the amount of water absorbed by the nodal roots per unit of dry weight.

From the results of this series of experiments one can conclude that in water cultures the investigated species of wheat and barley with a comparatively

weak seminal root system and profuse tillering accompanied by the formation of a rich nodal root system, *maintain the vitality and activity of the seminal roots up to the time of harvest.* These roots continue to function in the last periods of vegetation, supplying, in the conditions mentioned above, 20 to 25 per cent of the water and salts necessary for the plant.

TABLE 2

Total amount of water absorbed by each root system of wheat separately in three periods of development

PERIODS	NUMBER 5*			NUMBER 6*		
	Absorption of water.		Activity of seminal roots	Absorption of water		Activity of seminal roots
	Seminal roots	Nodal roots		Seminal roots	Nodal roots	
	cc.	*cc.*	*per cent*			*per cent*
I. June 23 to July 18	687.8	324.1	68	742.8	506.9	59
II. July 18 to August 3	277.0	431.3	39	308.7	879.4	26
III. August 3 to September 21	888.2	2287.6	28	878.0	4087.8	17
Total	1853.0	3043.0	38	1929.5	5474.1	26
	NUMBER 9*			NUMBER 10†		
	August 26 to September 21			August 10 to September 21		
	cc.	*cc.*	*per cent*	*cc.*	*cc.*	*per cent*
From heading to maturation	1103	3321	25	643	1660	28

* Two plants.

† One plant.

TABLE 3

Relative activity of seminal roots of wheat with different numbers of tillers and nodal roots

NUMBER OF JARS	NUMBER OF TILLERS	NUMBER OF NODAL ROOTS	NUMBER OF HEADS	ACTIVITY OF SEMINAL ROOTS
				per cent
5	11.5	23	7.0	28
10	17.0	..	8.0	24
9	14.0	18	10.0	23
6	14.5	48	12.5	18

The correlation between root activity and increase in growth of the main stem and tillers leads to the supposition that the seminal roots nourish principally the main stem, whereas the nodal roots work more for the tillers.

Experiments with summer rye were not completed because of the unexpected affection of rye by chlorosis at the period of flowering. The first half of these experiments, however, demonstrates the vitality of the seminal roots at least to the time of flowering. This summer rye resembled most summer field crops in that it had one or two tillers and five to ten nodal roots. As may be seen in table 6 their seminal roots performed over half of the work.

TABLE 4

Water and salt absorption, growth and development of barley no. 7

DATE	NUMBER OF DAYS	Average daily absorption of water: By the seminal roots	Average daily absorption of water: By the nodal roots	Average daily absorption of water: Total	Average daily absorption of water: Nodal root absorption per unit of seminal root absorption	Average daily absorption of salts: By the seminal roots	Average daily absorption of salts: By the nodal roots	Average daily absorption of salts: Total	Average daily absorption of salts: Nodal root absorption per unit of seminal root absorption	Amount of water absorbed per milligram of salt: By the seminal roots	Amount of water absorbed per milligram of salt: By the nodal roots
1	2	3	4	5	6	7	8	9	10	11	12
		cc.	cc.	cc.		mgm.	mgm.	mgm.			
June 25–30	5	3.1	0.5	3.6	0.16	..	..	..	....	....	....
June 30 to July 3	3	7.7	1.0	8.7	0.13	..	..	..	....	....	....
July 3–8	5	14.2	3.2	17.4	0.22	24	6	30	0.25	0.59	0.54
July 8–11	3	17.3	4.7	22.0	0.27	..	..	..	....	....	....
July 11–13	2	26.1	12.8	38.9	0.49	..	..	..	....	....	....
July 13–18	5	23.5	15.6	39.1	0.66	29	25	54	0.86	0.81	0.62
July 18–25	7	15.4	18.1	33.5	1.17	35	40	75	1.14	0.44	0.45
July 25–28	3	17.6	29.3	46.9	1.67	..	..	..	....	....	....
July 28–30	2	26.5	63.7	90.2	2.40	..	..	..	....	....	....
July 30 to August 6	7	14.1	42.2	56.3	2.99	28	88	116	3.14	0.50	0.48
August 6–9	3	22.0	73.4	95.4	3.33	..	..	..	....	....	....
August 9–11	2	14.7	46.7	61.4	3.17	..	..	..	....	....	....
August 11–17	6	14.8	60.5	75.3	4.09	25	74	99	2.96	0.59	0.80
August 17–20	3	22.2	87.3	109.5	3.93	..	..	..	....	....	....
August 20–23	3	16.1	62.3	88.4	3.87	..	..	..	....	....	....
August 23–29	6	26.2	82.4	108.6	3.14	39	60	99	1.54	0.67	1.37
August 29 to September 4	6	16.6	52.8	69.4	3.18	..	..	..			
September 4–10	6	12.3	34.4	48.7	2.79	39	57	96	1.46	0.31	0.60
September 10–15	5	12.9	35.0	47.9	2.71	..	..	..			
September 15–21	6	14.8	56.3	71.1	3.80	29	48	77	1.65	0.51	1.17

Development and growth in height: Date	Main stem: Stage of development	Main stem: Height to tip end of the leaf	Main stem: Average daily increase in height	Tillers: Number of tillers	Tillers: Summary height of all tillers to end of leaf	Tillers: Daily increase in height	Number of heads
13	14	15	16	17	18	19	20
		cm.	cm.		cm.	cm.	
June 28	3 leaves	32.0					
			2.1				
July 3	4 leaves Tillering	42.5		0.5	4.5		
			0.6			2.1	
July 10		46.0		1.0	19.5		
			0.9			7.1	
July 15	Stalking	49.5		2.0	55.0		
			2.1			12.0	
July 20		60.0		3.5	115.0		
			2.2			11.6	
July 25		71.0		4.0	173.0		
			0.6			11.4	
August 3		76.5		7.0	277.0		
			1.3			13.2	
August 11	Heading	87.0		8.0	483.0		
			0			14.7	
August 19	Flowering	87.5		8.5	601.0		2.5
			0			20.7	
August 27		87.5		11.0	766.0		2.5
						7.7	
September 6		....		12.5			6 0
September 21		....		12.5	958.0		6.5

EXPERIMENTS WITH THE REMOVAL OF ONE OF THE ROOT SYSTEMS

Methods

When the results of the first series of experiments are studied the objection might arise that because the seminal roots are active in water, this does not mean that they remain active in the soil where they may be unable to surmount less favourable conditions. Although the activity of seminal roots under soil

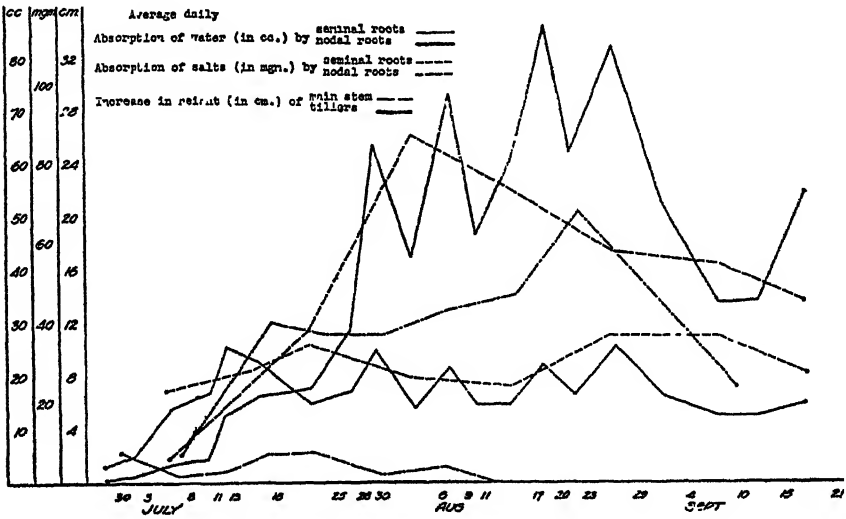

FIG. 3. WATER AND SALT ABSORPTION, AND GROWTH OF BARLEY NO. 7

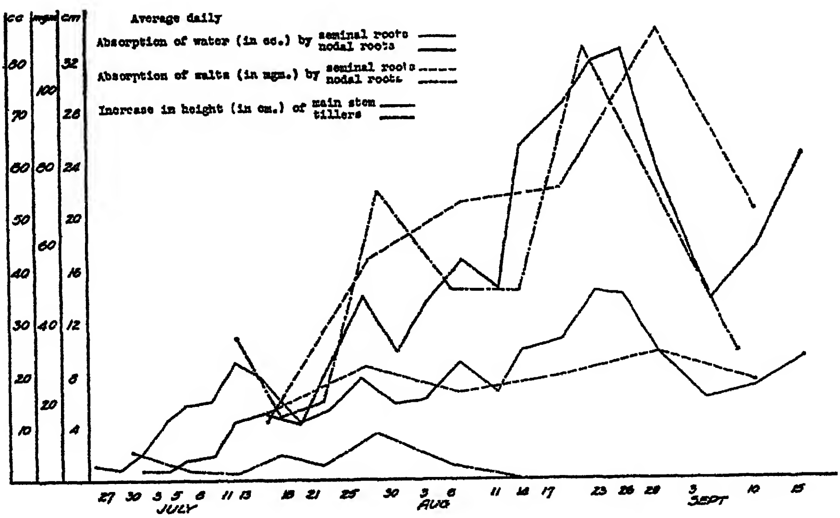

FIG. 4. WATER AND SALT ABSORPTION, AND GROWTH OF BARLEY NO. 8

conditions cannot be proved directly with the aid of water cultures, nevertheless indirectly their necessity may be demonstrated after the formation of the nodal root system. If at the time mentioned, the seminal root system be removed and this removal should perceptibly affect the plant or some part of it that develops normally in natural conditions, it may be concluded: first that these roots are necessary for the normal development of the plant; and secondly, that certain of the organs are more dependent on the given root system. It also seemed of interest to study the vitality and energy of both root systems; that

TABLE 5

Absorption of water by seminal and nodal root systems of wheat and barley in relation to dry weight of roots

PLANT AND NUMBER OF JAR	DRY WEIGHT OF ROOTS		AVERAGE DAILY ABSORPTION OF ROOTS PER GRAM OF DRY WEIGHT	
	Seminal	Nodal	Seminal	Nodal
	gm.	*gm.*	*cc.*	*cc.*
Wheat number 5	0.169	0.709	107	65
Wheat number 6	0.136	0.947	131	88
Barley number 8	0.135	0.650	326	173

TABLE 6

Activity of seminal roots in summer rye

PERIODS	NUMBER OF DAYS	NUMBER 1*			NUMBER 2*		
		Water absorbed		Activity of seminal roots	Water absorbed		Activity of seminal roots
		Seminal roots	Nodal roots		Seminal roots	Nodal roots	
				per cent			*per cent*
I. June 19 to July 3	14	90.6	42.3	68	48.7	11.3	81
II. July 3 to July 30	25	426.3	358.3	54	682.7	327.8	67

* Two plants.

is, how far they can substitute each other and whether the crop plant can accomplish its development with seminal roots only.

In this series 28 barley seedlings were transferred to 750-cc. bottles. Of these plants 7 served as controls (series I). From 6 of these plants the newly developing nodal roots were constantly removed (series II). From 5 other plants the seminal roots were removed after the beginning of stalking, when they possessed a developed nodal root system consisting of 10 to 17 roots and when their activity was overtaking that of the seminal ones, judging by the cultures with isolated root systems (series III). Recording methods were the same as in the preceding series of experiments.

Experimental data

Development and root activity of series I, II, and III: The main stem of the barley plants of series II developed normally as in the controls, ripening even

slightly sooner, but tillering very soon ceased, and only two or three tillers developed showing slight affection by chlorosis. In series III, where the seminal roots were removed, on the contrary, the main stem was affected most—it suffered from chlorosis and fell back in growth from the tillers. Though in each series the tillers were taller than the main stem, this difference between the main stem and the tallest tiller in the second series, averaged only 1.4 cm., 18 cm. in the controls, and 28 cm. in series III. The absence of nodal roots affected the quantity more than the quality of tillers. The absence of seminal roots affected the quality of the main stem, notwithstanding the vigorous development of the tillers. This fact again confirms the supposition that the seminal roots are necessary for the development of the main stem, whereas the nodal roots nourish the tillers. It is also interesting to note, that whereas the removal of the nodal roots hastened the process of ripening, the absence of the seminal roots retarded it.

The readings of salt absorption show that whereas in series II a maximum of salt absorption is reached at the time of stalking of the main stem, in series III this maximum is retarded to the time of stalking of the tillers. (Table 7.)

Concerning water absorption—the roots of series III did not eventually overtake the controls—the seminal roots of the controls seemed to supply an additional quantity of water up to the time of ripening. (Table 7.)

To a certain extent both root systems seemed to accommodate themselves to the new conditions, for their summary activity exceeded the activity of the controls. On the whole one may assert that both root systems are not capable of entirely replacing each other; for the harmonious development of summer crops both root systems are necessary.

Data of the yield. The total yields of plants in the different series were obtained in the order anticipated: series I yielded the largest total green or dry weight, then followed series III, and last series II. The relative development of different parts of the plant in connection with the presence of one or the other root system presented greater interest, for it proved that both systems are necessary to the plant in its last stages of growth.

Measurements of the size of the head and of the dry weight of the head or grain of the main stem (table 8) are higher in the series possessing seminal roots, and even greater in the second series, possessing seminal roots only, than in the first control series having both root systems. This may probably be explained by the phenomenon that the absence of the nodal roots stimulated the development of the seminal ones (table 9), which nourish the main stem.

The removal of seminal roots not only checked the growth of the main stem, but affected also the succeeding stages of the head and grain development as is shown in table 9. All this seems to prove that the seminal roots are necessary for the development of the main stem, and hence are active in the soil.

Table 9 shows that the removal of the nodal roots reduces the weight of the stems, whereas the yield of the ripe grain is decreased but slightly. On the

TABLE 7

Water absorption, salt absorption, growth and development of barley in the experiment series with removal of roots

I—control; II—nodal roots removed constantly; III—seminal roots removed. (All figures averages calculated to 1 plant.)

DATE	AVERAGE DAILY WATER ABSORPTION			AVERAGE DAILY SALT ABSORPTION		
	I	II	III	I	II	III
	cc.	cc.	cc.	mgm.	mgm.	mgm.
June 25–29	1.6	1.7	.....*	....	....	....
June 29 to July 1	4.4	4.2	.....	12.2	10.7	....
July 1–4	10.3	9.3	.....			
July 4–6	17.3	12.3	.....	12.5	....	....
July 6–9	26.6	22.8	.....			
Removal of seminal roots in series III						
July 9–11	43.3	34.3	33.1	48.7	31.3	24.6
July 11–14	70.3	49.5	54.2			
July 14–16	55.3	39.1	44.3	46.1	25.0	37.8
July 16–19	76.4	47.6	56.9			
July 19–21	37.9	23.0	34.5	45.6	28.4	41.9
July 21–26	72.3	41.1	55.2			
July 26–29	87.5	43.8	65.1	51.6	27.7	44.9
July 29 to August 1	96.6	53.7	76.6			
August 1–5	73.0	36.8	57.1	46.0	24.5	43.7
August 5–9	107.3	40.2	79.0			
August 9–12	65.4	28.2	50.9	....	....	....
August 12–15	143.7	52.2	112.6	....	....	....
August 15–18	58.3	19.3	47.8	52.8	21.4	59.0
August 18–21	145.6	54.1	118.1			
August 21–24	132.7	41.9	106.5	....	....	....
August 24–27	131.9	34.5	112.3	....	....	....
August 27 to September 3	118.7	26.6	94.8	38.1	16.5	50.9
September 3–8	74.5	14.1	56.5	....	....	....
September 8–13	43.7	9.0	36.7	....	....	....
September 13–17	96.3	15.5	76.9	....	....	....
September 17–20	65.0	10.3	52.7	....	....	....

DATE	AVERAGE DAILY INCREASE IN HEIGHT OF THE MAIN STEM			TILLERS: Number of tillers			TILLERS: Increase in height of all tillers			NUMBER OF HEAD		
	I	II	III	I	II	III	I	II	III	I	II	III
	cm.	cm.	cm.				cm.	cm.	cm.			
June 24	0.1	0.5	..				1.3	2.1	..			
June 29				0.7	1.0	...						
July 4	2.5	1.8	...	1.6	1.8	...	5.1	5.4				
	1.2	1.2					5.6	4.5				
July 9				2.0	2.0	...						
							4.5	1.9	3.6			
	1.8	1.2	0.6									
July 15				2.5	2.0	2.6						
	2.2	1.2	0.7				8.8	1.9	3.9			
July 20				3.3	2.1	3.0	12.3	3.4	8.5			
July 26	1.8	1.3	2.0	4.3	2.1	3.2	20.3	4.9	13.8			
July 31	0.5	0.2	0.2	5.7	2.6	4.6				1.0	0.8	0.8
	0	0	0				10.4	1.5	8.6			
August 8				5.8	2.5	5.0				2.4	2.3	1.6
							6.7	0.3	9.8			
August 15				8.0	3.0	6.2				3.8	2.8	3.4
							18.8	2.0	11.4			
August 22				9.6	2.7	6.8				5.1	3.1	3.8
							17.8	1.6	12.3			
August 29				10.8	3.0	8.6				5.8	3.1	4.8
September 6				10.8	2.8	8.6				6.7	3.1	5.4
							5.9	1.6	4.8			
September 17										7.0	3.3	6.0
September 20				11.0	3.1	8.6				7.0	3.3	6.2

* Before the removal of the seminal roots series III was combined with series I.

other hand, the removal of the seminal roots affects largely the yield of the ripe grain. In connection with the retarding influence of the absence of seminal roots upon the process of ripening, and the vigorous tillering, caused by the vigorous nodal root system, series III possesses a fair supply of unripe grain.

TABLE 8

Yield of tops, dry weight, and length of head of the main stem, and dry weight of tillers

(Average for each plant)

NUMBER OF SERIES	MAIN STEM				TILLERS			
	Dry weight			Length of head	Dry weight			
	Straw	Heads	Grain		Straw	Heads	Mature grain	Green grain
	gm.	*gm.*	*gm.*	*cm.*	*gm.*	*gm.*	*gm.*	*gm.*
I	0.886	1.466	1.256	8.07	7.88	6.659	2.43	2.333
II	0.894	1.585	1.335	7.66	1.94	2.704	1.19	0.915
III	0.813	1.024	0.812	7.20	6.04	4.635	0.30	2.790
IV	0.915	1.543	1.280	8.00	1.58	2.068	0.91	0.993

TABLE 9

Yield of roots and absorption of water, during the last month, per gram of dry roots

(Average calculated to 1 plant, in cubic centimeters)

NUMBER OF SERIES	NUMBER		LENGTH		DRY WEIGHT		DAILY WATER ABSORPTION PER GRAM OF DRY ROOTS	
	Seminal roots	Nodal roots	Seminal roots	Nodal roots	Seminal roots	Nodal roots	Seminal roots	Nodal roots
			cm.	*cm.*	*gm.*	*gm.*		
I	8.1	37.6	30.5	28.6	0.101	0.490*	152	
II	8.8	....	40.8	....	0.146	.....	137	..
III	...	41.8	....	29.0	.....	0.690	...	76
IV†	8.6	....	41.2	....	0.110	.....	150	..

* Some of the roots were badly torn and lost in the process of disentangling the seminal and nodal roots. This may partly explain the high figure of absorption per unit of dry weight in series I.

† Series IV, not mentioned in the text, consisted of only 3 plants, the nodal roots of which were not cut from the beginning of their development, but all simultaneously, 2 days after the removal of the seminal roots in series III. They thus had less time to adapt the development of their seminal root system, which is obvious from the data concerning their weight and the weight of the tillers as compared with series II.

As in the experiments with isolated root systems, the seminal roots absorb more water per unit of dry weight, than do the nodal ones (table 8). The latter may be of practical interest in solving the question: From what layers do the crop plants absorb water and minerals? Not only must the relative weight of roots at different depths be known, but also the energy of absorption per

unit of this dry weight. Most of the authors indicate that the main part of roots of grassy crop plants is distributed to the depth of 25 to 30 cm. Judging, however, by the illustrations of Schulze (13), Rotmistrov (12), and Weaver, Jean and Crist (20), the seminal roots grow more or less vertically into the depths of the soil; their weight is insignificant, but when their greater activity per unit of dry weight is taken into consideration[2] absorption from the deeper soil layers will prove greater than is generally accepted, and no doubt the seminal roots play a greater rôle in plant nutrition than as yet has been assigned to them. This may be the case particularly in conditions where the crops develop not more than one or two tillers and in consequence few nodal roots.

The aim of this work was to investigate whether the seminal roots continue to function after the formation of the nodal root system and, further, to examine the rôle of the former in the supplying of water and nutrients and how far they may guarantee the crop in the case of inhibition of nodal root formation. Insofar as concerns barley, wheat, and rye in water cultures, the answer is positive.

Experiments of Wiggans (21), Walworth and Smith (17), and Sieglinger (15) have shown that not only different kinds, but also different varieties of the same crop plants do not possess the same number of seminal roots. Observations of wheat in water cultures (19) have also shown that seminal roots may attain lengths from 40 to 110 cm. Obviously in the case of the appearance of conditions unfavorable for the development of nodal roots, the advantages will be on the side of the varieties possessing a more vigorous seminal root system. Before drawing any conclusions, however, it is essential to verify the activity of seminal roots in soil cultures.

The above mentioned experiments were carried out in the summer of 1923. In the summer of 1924 the second series of experiments was repeated, with modifications, in soil cultures with summer barley. The results more or less confirm those obtained in water cultures, but as the data have not been compiled, more detailed results of the soil experiments will form the subject of another paper.

SUMMARY

1. Experiments were carried out with summer wheat, barley, and rye in water cultures with isolated nutrition of seminal and nodal roots.

2. Records of water and salt absorption have shown that the seminal roots are active up to the time of harvest and supply two or three stems of the plant with nutrients.

3. The correlation between the time of maximum activity of the seminal

[2] Probably the same activity may be assigned to the ends of the nodal roots in the greater depths where they acquire the slenderness of seminal roots, whereas the upper part of the nodal roots forming the heavy bulk does not take part in the absorption.

roots and the maximum growth of the main stem as well as between the time of the maximum activity of the nodal roots and the maximum growth of the tillers seems to prove that the seminal roots supply principally the main stem; the nodal roots, the tillers.

4. The decrease in activity (amount of water absorbed) caused by the removal of either the nodal or the seminal root system is never entirely completed during the whole vegetative period by the remaining root systems.

5. The removal of the seminal roots in the period of stalking suppresses the development of the main stem and lengthens the period of vegetation: this evokes the supposition that the seminal roots are indispensable for the normal development of the crop plant and are consequently active in the soil.

6. The removal of the nodal roots checks tillering, hastens maturing, does not affect the quality of the grain of the main stem, nor even that of the first tiller.

7. These last two points confirm the conclusion drawn from the first series of experiments that the seminal roots serve the main stem, whereas the nodal roots serve the tillers.

8. Whereas the removal of the seminal roots decreases the yield of grain, the removal of the nodal roots decreases principally the yield of straw.

9. The removal of the nodal roots stimulates the growth and activity of the seminal roots.

10. The seminal roots absorb almost double the amount of water per unit of dry weight in comparison to the nodal roots.[3]

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PLATE 1

FIGS. 1, 2, 3. DIAGRAM OF JARS USED IN ROOT STUDIES

Fig 1

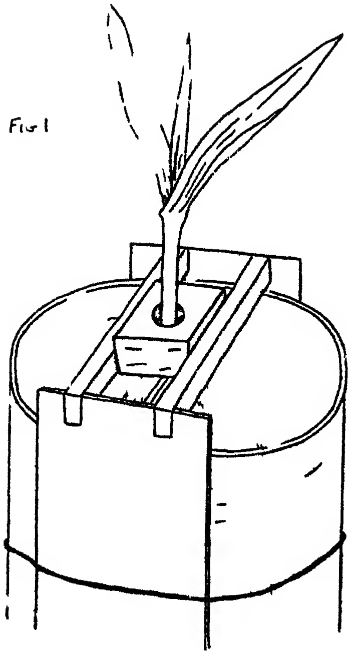
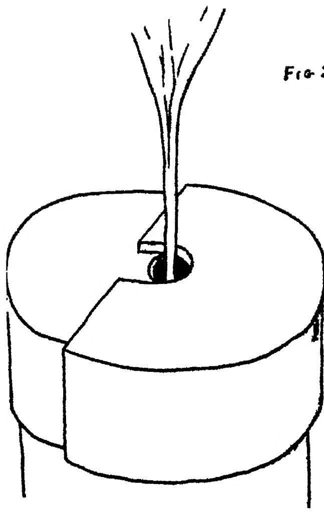


Fig 2



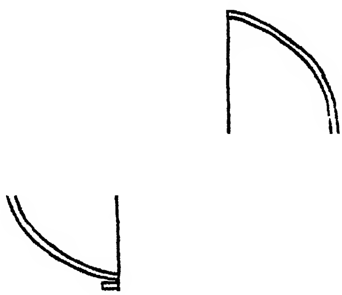


Fig 3

PLATE 2

(Photographed August 15, at time of flowering)

Left, experiments with isolated root systems. From left to right: Wheat No. 6; Barley No. 8; and winter rye (not mentioned in the text).

Right, experiments with the removal of one of the root systems. The main stalk is marked "M." From left to right: Series III—seminal roots removed; series II—nodal roots removed; series I—control.

(Note character of root system and relative amount of water absorption for the same period of time.)

THE PROBLEM OF A PROPER NUTRIENT MEDIUM[1]

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PART I—HISTORICAL[2]

Starting out to study the assimilation of various phosphates in sand cultures (1896) the senior author encountered a condition in which the nutrient solution of Hellriegel and Knop did not prove satisfactory. Occasionally some plants capable of efficient assimilation of phosphates (buckwheat, lupines) developed rather poorly on the culture solution of Hellriegel. The growth was poorer than with a nutrient solution in which a combination of phosphate and some neutral salt of potassium (KCl, K_2SO_4) was substituted for the potassium acid phosphate.

Two conditions might have been responsible for the observed phenomenon:

1. The acid reaction of the medium (pH 3.6 to 3.7) may not be tolerated equally by all plants. 2. During the growth period a neutralization of the solution and an accumulation of the titrable alkalinity take place.

The $CaNO_3$ as the chief constituent of the solution is unequally utilized; the NO_3 is assimilated faster; the excess of Ca remains behind as $Ca(HCO_3)_2$. *This brings about a low assimilation of iron and phosphorus.*[3]

The chief interest was then to see whether plants are capable of assimilating insoluble phosphates; for that reason the alkalinity of the solution of Hellriegel appeared to mark the ability of some plants to utilize the phosphorus from phosphates.[4] This stimulated interest in finding a nutrient solution which should not tend to become alkaline but which should retain its original neutral reaction.

As NH_4Cl and $(NH_4)_2SO_4$ salts are known to be physiologically acid and therefore unsuitable as nitrogen sources for water and sand cultures it was natural to look for a different nitrogen source. In 1900, in experiments insti-

[1] Translated from the Russian manuscript by J. S. Joffe, New Jersey Agricultural Experiment Station.

[2] For the historical portion of the paper the senior author only is responsible.

[3] For this reason an addition of acid (HCl) at some time of the experiment improves the growth of the plant in the Hellriegel solution.

[4] In the presence of $Ca(NO_3)_2$ only a few plants like lupines, buckwheat, peas, and mustard possess this ability; the majority, however, have not shown it.

tuted to test such a nutrient[5] the following various proportions of NO_3 and NH_4 were introduced: 1:0, $\frac{3}{4}$:$\frac{1}{4}$, $\frac{1}{2}$:$\frac{1}{2}$, $\frac{1}{4}$:$\frac{3}{4}$, 0:1. Two series of experiments were run: in one series the source of phosphorus was $Ca_2H_2(PO_4)_2$; in the other an excess of alkali was used to depress the possible physiological acidity of the $Ca_2H_2(PO_4)_2$.

Table 1 gives the plan and the results of the experiments.

In the series with $Ca_2H_2(PO_4)_2$, the absolute quantities of P_2O_5 (in the order of nitrogen sources as shown in table 1) in the crop were as follows: 155, 153, 254, 244, and 77 mgm.

These experiments have shown that the introduction of equal amounts of NO_3 and NH_4 [in the form of NH_4NO_3 or $(NH_4)_2SO_4$ and $NaNO_3$] does not create a physiologically neutral medium; but one which has a tendency to become acid. Under such conditions the phosphoric acid of the phosphates becomes available to the grain crops, which are not capable of utilizing it in the presence of nitrates.

TABLE 1

Plan and results of nitrogen nutrient tests

	SOURCE OF NITROGEN					
	$NaNO_3$	$\frac{3}{4}$ $NaNO_3$ $\frac{1}{4}$ $(NH_4)_2SO_4$	$\frac{1}{2}$ $NaNO_3$ $\frac{1}{2}$ $(NH_4)_2SO_4$	NH_4NO_3	$\frac{1}{4}$ $NaNO_3$ $\frac{3}{4}$ $(NH_4)_2SO_4$	$(NH_4)_2SO_4$
Yield of oat tops *mgm*.	6.90	22.0	20.50	18.90	19.20	1.60
P_2O_5 in crop *per cent*.	0.09	0.3	0.57	0.53	0.92	1.46
Total P_2O_5 *mgm*.	6.20	66.0	116.80	105.40	176.60	24.10*

* A photograph of the cultures may be found in the book of the senior author: "Düngelehre," Paul Parey, Berlin, 1922; also in Land. Ver. Sta. 56, 1902.

In 1901, in experiments (20) conducted with the purpose of testing various sources of nitrogen and phosphorus, the combination NH_4NO_3 and $Ca_2H_2(PO_4)_2$ proved to be the best; a litmus test of the sand of the $NH_4NO_3-Ca_2H_2(PO_4)_2$ series after the crop was harvested showed a tendency to maintain a neutral reaction.

On the basis of the aforementioned experiments, the senior author suggested as an appropriate medium for sand cultures the use of $Ca_2H_2(PO_4)_2-NH_4NO_3$ in place of the combination of $Ca(NO_3)_2-KH_2PO_4$, used in the Hellriegel medium. The addition of gypsum compensated for the lack of Ca. In this medium the slight (as was then thought by the author) physiological acidity of the NH_4NO_3 produced by the formation of small amounts of HNO_3 was supposed to be balanced by the buffer action of the $Ca_2H_2(PO_4)_2$.[6]

[5] In all cases, unless otherwise stated, sand cultures were used. The sand was washed with strong HCl.

[6] In the beginning it was thought that the slight tendency toward acidity and decomposi-

The composition of the medium per kilogram of sand was, therefore, as follows: NH_4NO_3—0.24 gm., $Ca_2H_2(PO_4)_2$—0.172 gm., KCl—0.15 gm., $MgSO_4$—0.6 gm., Fe_2Cl_6—0.025 gm., $CaSO_4 \cdot 2H_2O$—0.344 gm. The medium is identical with that of Hellriegel in the amounts of the various elements except sulfur, which was in excess because of the addition of gypsum.

The new medium was known in the laboratory as the neutral medium or "Prianishnikov medium."

In later years, this medium was used very extensively parallel with the Hellriegel medium. The experiments conducted concerned the problem of the assimilation of the various sources of phosphorus and potassium in sand cultures. The data in table 2 are just a few typical experiments conducted in 1904; they show a similarity in yield on the author's and on Hellriegel's (22) media.

TABLE 2

The yield of oats, sunflower, and buckwheat on Prianishnikov and Hellriegel media

EXPERIMENT	YIELD ON HELLRIEGEL MEDIUM	YIELD ON PRIANISHNIKOV MEDIUM
	gm.	*gm.*
On oats 1	25.8	29.3
On oats 2	22.3	22.6
On oats 3	30.4	31.2
On sunflower	14.2	23.0
On buckwheat	23.3	17.2

TABLE 3

Analyses of plants in various media

MEDIUM	YIELD	N	K_2O	P_2O_5	CaO	SO_3
	gm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
Hellriegel	21.46	413	644	99	212	120
Prianishnikov	21.73	402	715	91	113	200
Crone	21.33	357	510	73	235	184

tion of phosphates was due to nitrification, although the experiments were conducted in sand washed with HCl; experiments in sterilized cultures (20) repeated by Kossovitz (15) and Shulov (25) showed the same phenomenon. Later, following the author's suggestion, Shulov conducted experiments with the view of clearing up the rôle of plants in the process of decomposing the phosphates with NH_4NO_3; the method used was a division of the roots in various media. It was shown that the separation of the alkaline $Ca(NO_3)_2$ preventing its reacting with the phosphates does not change the relation of the grain crops to the phosphates; only the introduction of NH_4NO_3 calls forth the solubilization of phosphates under the influence of the roots of grains. Thus there was no other explanation for the observed phenomenon than to attribute it to the NH_4NO_3 producing a physiologically acid reaction. For a more detailed account the reader is referred to the Russian paper of Shulov (25), also the author's German paper (21, p. 47).

The irregularity of the results in experiments with various plants indicated the necessity of a closer study of the problem, but due to the pressure of other work it was postponed and no new experiments were conducted until the years 1911 to 1916.

In general these experiments corroborated the results for the sand cultures, but for the solution cultures the use of the new medium showed some limitations.

Just a few of the experiments with sand cultures will be reported.

In 1912 the experiments of Shulov (26) under sterile conditions showed that the young plants of corn and peas were assimilating more ammonia nitrogen than nitrate nitrogen from NH_4NO_3; thus it was proved that the NH_4NO_3 is a physiologically acid salt.

TABLE 4

Crop yields in various media

	PRIANISHNIKOV MEDIUM	HELLRIEGEL MEDIUM	CRONE MEDIUM	ALKALINE* MEDIUM
Alkalinity after harvesting the second crop, 0.1 *N* alkali	1.09	1.37	1.95	2.15
The yield of the third planting *gm*	19.56	16.55	14.25	12.70

* Under alkaline we understand a change of the Hellriegel medium whereby one-half of the nitrate of calcium has been replaced with nitrate of potassium. The titration was conducted with methyl orange.

TABLE 5

Effect on plants of introducing mono-calcium phosphate into Prianishnikov medium

	YIELD OF MILLET	YIELD OF FLAX	YIELD OF GARDEN CRESS
	gm.	*gm.*	*gm.*
Di-calcium phosphate	32.9	15.0	13.9
Mono-calcium phosphate	5.09	4.5	Plant died

In 1914 Stolgane (30) studied the intake of nutrient substances from the media of Hellriegel, Prianishnikov, and Crone (3). The plants were analysed at four stages of their growth. The results are given in table 3.

These data show than in the first two media the conditions for the assimilation of nitrogen, phosphorus, and potassium are similar; for it was observed that the Crone medium hindered assimilation of phosphorus although without effect on the yield.

In connection with the work of Whitney and Cameron (33) in regard to the drop of yield in continuous culture, the effect of the kind of medium on the behavior of plants was studied in sand cultures. The titratible alkalinity of the media after the harvest of each crop, was determined and the yield of the continuous plantings was found to be lower as the alkalinity increased. This

alkalinity remained from the previous plantings and therefore the continuous plantings gave better yields on the medium proposed by the author than on other media; as an example we shall take the figures of the titration of an extract from a sand culture after the second crop was harvested and the yield of the third crop of lupines.[7]

As one may see from the figures, the yield of each succeeding crop is decreased as the medium becomes more alkaline on account of the growth of the plants.

In comparing the relation of the various plants and media, we did not limit ourselves to the aforementioned media in their original form. Experiments were conducted for each of 15 media in order to clear up the reasons for the success of one and the failure of the other in their applications to various plants. This brought about a rather complicated series of experiments (12).

As one would expect, two components; namely, the source of nitrogen and the source of phosphorus, are the outstanding features in a 3-salt medium. In

TABLE 6

Effect on plant growth of introducing various phosphates into the Hellriegel medium

	OATS	WHEAT	MILLET
	gm.	*gm.*	*gm.*
Primary phosphate	13.7	9.2	16.1
Secondary phosphate	6.1	4.8	....
Tertiary phosphate	6.7	5.4	5.8

TABLE 7

Relation of grain to straw with various media

MEDIUM	SOFT WHEAT	HARD WHEAT	BARLEY	OATS
Hellriegel	0.28	0.16	0.45	0.42
Prianishnikov	0.77	0.67	0.72	0.54
Crone	0.65	0.47	....	0.38

the Hellriegel medium the two components are $Ca(NO_3)_2$ and KH_2PO_4; in the Prianishnikov medium—NH_4NO_3 and $Ca_2H_2(PO_4)_2$; in the Crone medium—KNO_3 and $Fe_3(PO_4)_2$.[8] If the mono-calcium phosphate instead of the di-calcium phosphate is introduced into the Prianishnikov medium the plants suffer from an acid reaction as shown in table 5.

The introduction of $Ca_3(PO_4)_2$ is favorable to growth in the presence of NH_4NO_3. On the other hand the introduction of secondary and tertiary phosphate in place of the primary phosphate in the Hellriegel medium hampers the conditions for growth.

[7] Each planting was allowed to develop for one month; the plants were then removed and another planting with the addition of another portion of salts was made without washing the sand.

[8] Besides this the Crone medium contains also $Ca_3(PO_4)_2$.

The same results may be inferred from the Crone medium with its KNO_3, $Fe_3(PO_4)_2$ constituents. Although Crone does not propose these constituents, the author's experiments with the introduction of the ammonium nitrate show that it influences unfavorably the assimilation of P_2O_5 from iron phosphate, since it creates a weakly acid reaction, whereas KNO_3 brings about a weakly alkaline reaction, and thus favors the assimilation of P_2O_5 from the iron phosphate.[9]

The solution of the problem as to which of the media is the best was complicated, since the various plants behave differently with the changes in the reaction of the medium and are different in their requirements of the nutrient substances and of their assimilation, and therefore are incomparable in the various media; and besides the order of behavior of the various plants toward this or the other medium differed with the various years.[10]

Without entering at this time into an analysis of the complexity of the results, a few variations noticed in the plants may be cited. These variations may be divided into the following groups:

First: For certain plants a neutral medium seems to be better than the medium of Hellriegel and Crone; this is regularly observed in cases of garden cress, in the majority of cases with flax, and occasionally for poppy seed and buckwheat.

Second: In a series of cases this medium from the standpoint of yield was very close to that of the Hellriegel medium, but either one was lower than the medium of Crone (wheat, oats, barley, corn, turnips, sugar beets, potatoes, buckwheat). The relation of grain to straw was infrequently more normal with this medium than with the other media; for instance in 1914 the differences shown in table 7 were noticed (12).

Third: The neutral medium appeared to be worse than the Hellriegel and the Crone media for peas and lupines, and partially so for sunflower; for buckwheat great variations were noticed beginning with the first and ending with the third group.

[9] In the experiments with iron phosphate the following results (2) may be cited.

	YIELD OF BARLEY	AMOUNT OF P_2O_5 IN CROP
	gm.	*mgm.*
$FePO_4 + NH_4NO_3$	7.2	41.3
$FePO_4 + CaCO_3$	19.1	63.7

Introduction of $CaCO_3$ with $Ca_3(PO_4)_2$ brings about a depression.

[10] One of the experiences with this phenomenon may be found in the following condition: If the water is introduced from the bottom, as it is in this laboratory, the soluble salts may accumulate in the surface layer, if evaporation from the surface of the vessel is increased; the insoluble portion of the medium remains uniformly distributed throughout the vessel; it is thus possible that for a short period the acid reaction caused by the one-sided utilization of the ammonium nitrate is not balanced throughout the various layers in the vessel. Although water is applied periodically to the surface of the cultures, there is still the possibility that a physiological acidity should appear more pronounced in the surface of the vessel than in the lower portion. Since the movement of the salts toward the surface depends upon the components of the sand, upon the size of particles, upon the method of watering, and upon weather conditions, it is possible that this is the cause of the irregularity that occurred during the various years.

Since in those years the method of determining the hydrogen-ion concentration was not practiced, an analysis of the results was somewhat difficult; in 1917 the war conditions caused a break in the work. Only in recent years was there a chance to return to the study of the relation of the plants and the components of the media, with the possibility of determining the changes in the hydrogen-ion concentration under the influence of the plants. This part of the work, which presented a clear picture of the relation of the plants to NH_4NO_3, is given in the latter part of this paper.

An opinion was expressed (10) that the medium proposed by the author should be applicable also to solution cultures. However, experiments have shown that under such conditions the medium has a tendency to become more acid, as in the case of the sand cultures, and for that reason the yields at their best are

TABLE 8

Reactions of Hellriegel and Prianishnikov media with barley and buckwheat

MEDIUM†	BARLEY	BUCKWHEAT
	*cc.**	*cc.*
Hellriegel	+2.5	+0.5
Prianishnikov	−0.6	−1.2

* cc. 0.1 *N* alkali per 100 cc. of solution; + indicates an increase of alkalinity; − an increase of acidity; the titration was conducted with methyl orange.

TABLE 9

Behavior of barley and flax in various media studied in sand and solution cultures

MEDIUM	BARLEY		FLAX
	Sand cultures	Solution cultures	Solution cultures
	gm.	*gm.*	*gm.*
Hellriegel	11.7	11.3	12.8
Prianishnikov	11.3	2.6	4.5
Crone	11.4	12.4	12.5

only equal to those which are obtained with the Hellriegel medium—at times even worse. The author was forced to the conclusion that in its original composition the medium proposed for sand cultures may not be recommended for solution cultures. That the movement toward acidity is responsible for this may be proved by the fact that a replacement of the di-calcium phosphate with the mono-calcium phosphate has a still worse influence on the plants; and besides an analysis of the solution after the experiment, showed a noticeable titratable acidity in those cases where the plants showed injury. Thus in the experiments of Arnold (1), the shifting of the reaction as compared with the original was measured as indicated in table 8.

It is interesting to note that in this experiment the buckwheat on the Prianishnikov medium shows symptoms of injury. The yields in this experiment did not vary sharply (11.4 and 11.1 gm. for the barley; 7.75 and 6.25 gm. for buckwheat); in the experiments of 1913 conducted by Stolgane (30) the results for the water cultures were unfavorable, also from the standpoint of yield.

As far as the differences in behavior of the media studied in sand and in solution cultures are concerned the following may be suggested:

First: The distance separating the precipitated phosphate in the ammonium nitrate cultures has its influence; it is possible that at a slow rate of diffusion the root hairs may accumulate around themselves an injurious degree of acidity, which in this case was eliminated only once in 24 hours by stirring.[11] Later experiments have shown that mature plants are capable of changing the reaction within 2 hours, and that the reactions of ammonium nitrate solutions approach those of ammonium chloride solutions.

Second: The question was raised whether in the case of the sand cultures adsorption influences in one way or another the composition of the medium, making it more favorable

TABLE 10

*Results of experiments conducted during 1916**

MEDIUM†	YIELD OF BARLEY		YIELD OF OATS		YIELD OF RYE	
	Without charcoal	With charcoal	Without charcoal	With charcoal	Without charcoal	With charcoal
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Hellriegel	17.1	....	16.4	31.8	....	....
Prianishnikov	22.0	32.7	....	....	13.0	18.8
Acid	16.6	33.5	6.5	25.7	14.4	59.0
Alkaline	16.5	29.5	12.2	25.9	8.3	17.5

* Jakushkin, I. V. On the influence of finely ground charcoal on the yield with different nutrient media in sand cultures. (Experiments conducted in the laboratory of Prianishnikov in 1916. Not published.)

† Under the acid medium we understand the Hellriegel medium replacing $Ca(NO_3)_2$ with NH_4NO_3, and alkaline medium—the medium of Hellriegel replacing a half of the $Ca(NO_3)_2$ with KNO_3.

for the plants, or whether it influences the shifting of the reaction from the neutral point. The latter assumption was confirmed by the fact that finely granulated charcoal introduced into the medium obliterated the shifting of the reaction.

Thus charcoal is capable of eliminating the injurious influence of the reaction's shifting either towards acidity or alkalinity: this is in accordance with the data concerning the ability of charcoal to absorb energetically the H and OH ions as pointed out by Michaelis (16). For the sand, however, no such

[11] That the formation of a precipitate on the bottom of a vessel may be a factor in hindering the development of the plants may be deduced from the experiments conducted in the laboratory by M. I. Sidorin (27, 28); it was shown that the plants may suffer from chlorosis even though iron phosphate is present at the bottom of the vessel; whenever the distance between the roots and the bottom of the vessel was appreciable and the stirring was not done frequently enough.

phenomenon could be observed, although it is known that the absorption phenomenon in general is demonstrable in the sand culture results.[12]

Coming back after a time to the study of the individual components of the author's medium and utilizing the methods of determining the hydrogen-ion concentration, the authors have shown that the physiological acidity of NH_4NO_3 was more pronounced than it was ever supposed; it seems that the plant is capable of making this medium in certain movements just as acid as with ammonium chloride.

The experiments of Domontovitch described later have shown that the more developed plants, after 2 hours contact in a solution of ammonium nitrate and ammonium chloride, are capable of changing appreciably the pH of the solution; the experiments of Kupreyenok[13] conducted in 1922 show that in a vessel of small volume, plants are capable of changing the reaction of the medium from pH 6.2 to 3.9 within 24 hours. (This experiment was conducted under conditions of changing the solutions and it was apparent that with ammonium salts a change of the medium every other day does not prevent a shifting of the reaction).[14]

This explains the fact that in culture solutions stirred once in 24 hours, the presence of ammonium nitrate in solution and of di-calcium phosphate as a precipitate does not eliminate the unequal accumulation of acid; the latter may therefore become concentrated around the roots in undesirable quantities.

In an effort to determine which one of the unknown causes plays a more important rôle in the irregularities noticed between solution cultures and sand cultures, the improvement of the author's medium for solution cultures may be sought in two directions:

First: With the same source of P_2O_5—$Ca_2H_2(PO_4)_2$—to increase the ratio of NO_3 to NH_4NO

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[12] To check the assumption on the rôle of absorption in regulating the reaction O. V Saroobina conducted the following experiments: Sand washed with strong HCl was moistened with a solution of one of the nutrient media (Hellriegel, Prianishnikov, Crone) and upon the expiration of one hour, a replacement of the solution by means of alcohol following the method of Istserekov (9) was carried out. The replaced solution was analyzed for all the cations and anions introduced and was compared with the original composition. However, the experiments were not successful in establishing any relation of the sand to the component parts of the medium, which contains ammonium nitrate as compared with other media. In checking up the second variable on the rôle of absorption, it was apparent that the sand used was capable of weakening somewhat the acid reaction of the solution in contact with it; for instance, the medium having an initial pH of 3.92 gave a pH of 4.76 after coming in contact with the sand; the solution, which was alkaline, did not change upon contact with the sand. This phenomenon may be explained not only by adsorption but by the impurities found in the sand which are capable of neutralizing acid solutions.

[13] Kupreyenok. On the speed of reaction changes in solution by plants with various sources of nitrogen. (Investigation conducted in the laboratory of Prianishnikov during 1922. Not published.)

[14] That the change of the solutions does not prevent the appearance of injurious influences on the part of the physiologically acid salts was observed in 1908 but there were no determinations of pH made then.

($\frac{3}{4}$ or $\frac{7}{8}$). This change is corroborated by the work of various American workers, such as Wolkoff (34).

Second: By increasing the amount of base which is carried with the phosphates; that is, to try the influence of $Ca_3(PO_4)_2$ in place of $Ca_2H_2(PO_4)_2$. Incidentally, in sand cultures it has been repeatedly noticed that an improvement of growth is marked by replacing the di-calcium phosphate with freshly precipitated tri-calcium whenever the source of nitrogen was NH_4NO_3. However, more experiments in this direction are desirable.

As was shown in the experiments of 1911 to 1916, among other media, various modifications of the Crone media were used; by itself this medium appears to be universal, giving in most cases very good results (except with garden cress and partially with flax), also giving regular yields of rye in both sand and water culture; still this medium may be improved. Thus, by making several changes in this medium it was observed that by replacing the $Fe_3(PO_4)_2$ with $Fe_2(SO_4)_3$, and increasing the portion of $Ca_3(PO_4)_2$ to keep up the P_2O_5 content,

TABLE 11

Results with corn plants grown for 10 days in various media (24)

EXPERIMENT	AMMONIUM NITRATE		AMMONIUM CHLORIDE	
	Before experiment	After experiment	Before experiment	After experiment
	pH	*pH*	*pH*	*pH*
1	7.0	3.7	6.9	3.7
2	7.0	3.9	6.9	4.0
3	6.8	4.2	...	...
4	6.8	4.1	...	...

TABLE 12

Results of Jakushkin's experiments on modified Crone medium

MEDIUM	MILLET	BUCKWHEAT	LUPINES
	gm.	*gm.*	*gm.*
Original Crone	33.3	11.8	21.7
Modified Crone	48.2	17.8	26.5

the yield was increased. Table 12 taken from the experiments of Jakushkin (12) gives the results on the modified Crone medium.

The modified Crone medium[15] infrequently gave better results than any other media. When these experiments were conducted, the present day methods of determining the reaction had not been introduced, but there is reason to suppose that the same medium is capable of keeping the reaction within limits. Besides the forms of the compounds, this medium differs from Knop's and

[15] The modification makes the medium a non-Crone medium, since the characteristic of the Crone medium is the presence of iron phosphate. The modification is similar to the Sax medium, except that the former contains less salts of iron and the latter contains NaCl.

Hellriegel's media by a larger amount of soluble salts; this concentration of salts is tolerated because they are neutral salts. It is worth mention that a certain increase in the osmotic pressure through salts ineffective from the standpoint of nutrition may also be useful, as shown by Malioushitsky and Tulaikov (32). In the author's cultures there was not only an increased assimilation of nitrogen under the influence of NaCl (29) but also a greater accumulation of oil in the seeds of flax and of mustard, an increase in the percentage composition of sugar in tomatoes, and also an increase in the soluble carbohydrates in the vegetative portion of the grain crops.[16]

It is thus possible that in the Crone medium besides the forms of the nutrient salts, the increased concentration of the nutrient solution, which was made possible by the exclusion of the acid phosphate, also has an influence.

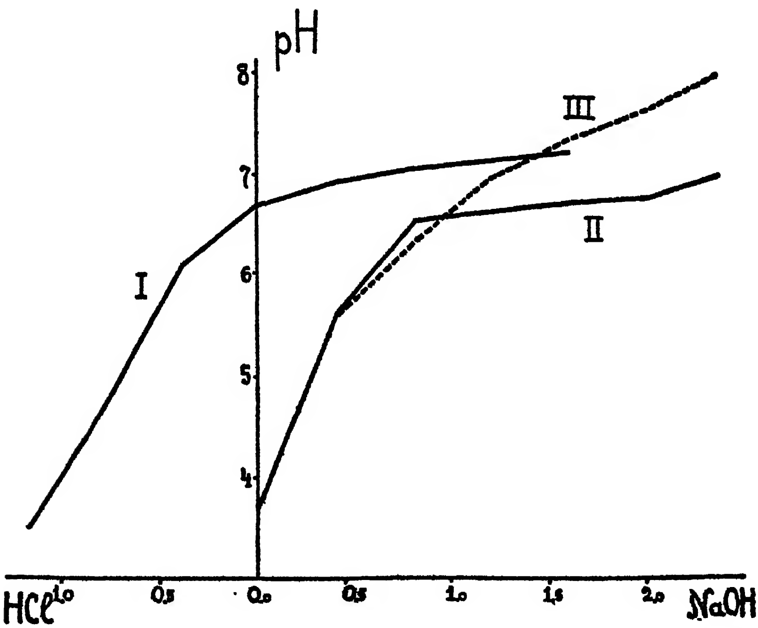

FIG. 1. GRAPHS SHOWING THE TITRATION OF THE PRIAMSHNIKOV AND HELLRIEGEL MEDIA AT START (I), AFTER 24 HOURS (II), AND AFTER ½ HOUR (III)

PART II[17]

The experiments described below are a continuation of the investigations of Prianishnikov reported in the first part of this paper.

Special emphasis has been laid on the factors influencing the reaction of

[16] Pereturin. On the influence of osmotic pressure of the solutions on the composition of plants. (Investigation conducted in the laboratory of Prianishnikov in 1922. Not published.)

[17] The text of this second part has been prepared by M. K. Domontovitch.

nutrient medium during the growth period of plants. The factors of the dynamics of the reaction of nutrient media investigated were as follows:

1. Physiological acidity or alkalinity of the nitrogen sources, NH_4 or NO_3. 2. The buffer action of the media. 3. Specificity of plant species.

The course of the reaction in solution cultures was the subject of investigation by Duggar (4), Jones and Shive (14), Hoagland (8), Theron (31), and others. Recommendations of a special nitrate ammonia medium are given in the work of Wolkoff (34) and Hartwell and Pember (5). The latter attempted to control the reaction by the combination of $NH_4 + NO_3$; thus the recommendation of Hartwell and Pember coincides with that of Prianishnikov. The difference consists in that in the Prianishnikov medium the buffer action of di-calcium phosphate is utilized along with the physiologically acid ammonia nitrate. A series of interesting observations on the question of the physiological acidity of ammonium salts was made by Olsen (17), Jacobs (11), Hoagland and Davis (8), and Jones and Shive (14). During the progress of the work the aforementioned investigations were not available to the author and could not be utilized. Besides, their work dealt chiefly with solution renewal whereas the work of the author deals chiefly with constant media.

Buffer action of the Hellriegel and Prianishnikov media

The original reaction of these media is controlled chiefly by the phosphates, KH_2PO_4 or $Ca_2H_2(PO_4)_2$, and by $FeCl_3$. The changes in reaction of these media upon the addition of NaOH or HCl are shown in figure 1. The method used in obtaining these curves was as follows:

Into a series of flasks, 100 cc. of the respective media was poured and additions of 0.1 *N* NaOH or HCl were made. The pH determinations were made with the Quinhydrone electrode after 24 hours and for the Hellriegel medium also after 30 minutes (dotted line of the curve).

A comparison of the pH value of the Hellriegel medium after 30 minutes and after 24 hours shows that the pH of this medium does not attain its equilibrium at once; it depends on the precipitation of the phosphates of calcium. On account of the large amount of $FeCl_3$ (about one-half to a milliequivalent per liter) the original reaction of the Hellriegel medium is strongly acid (pH 3.6 to 3.7). In solution cultures such a reaction may exert an injurious influence on the roots of young plants of several species. In sand cultures where the sand is practically never absolutely pure, but contains some neutralizing properties, the critical acidity produced by a large amount of $FeCl_3$ does not show itself. According to some calculations, a titration with phenolphthalein should give an acidity equivalent to 2.5 cc. of 0.1 *N* NaOH for every 100 cc. of the Hellriegel medium (since the medium contains a millimol of KH_2PO_4 with an excess of calcium and approximately half a milliequivalent of $FeCl_3$). This titration does not take into consideration the acidity produced by the

CO_2. The amount of alkali necessary to bring about a pH of 7.0 in the Hellriegel medium is not regular, but depends upon the time the reading is taken.

The original reaction of the Prianishnikov medium is close to that of the neutral point; namely, pH 6.6 to 6.7. In order to acidify it and to bring it to a pH 4.0, 0.9 to 1.0 cc. of 0.1 *N* HCl is necessary. Thus, as the Prianishnikov medium shows a clear buffer action against acidifying, one may find a justification for the combination of the physiologically acid ammonium nitrate with di-calcium phosphate; the latter is capable of absorbing the H ions and of

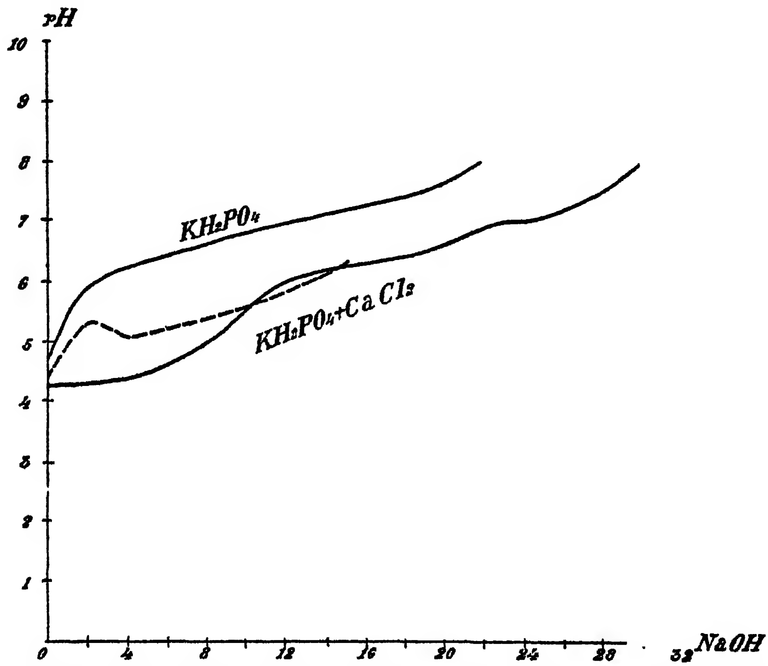

FIG. 2. GRAPHS SHOWING THE TITRATION OF 0.05 *M* SOLUTION OF KH_2PO_4 AND 0.05 *M* KH_2PO_4 + 0.02 *M* $CaCl_2$

changing into the mono-phosphate. However, this buffering property of the Prianishnikov medium is not sufficient in some cases. It would be interesting to increase the buffer properties of this medium by increasing the amount of di-calcium phosphate or by replacing the $FeCl_3$ with iron tartarate or something similar.

In order to illustrate the influence of the precipitation of phosphates of calcium on the titration curve, figure 2 is given, in which the titration graphs of 0.05 *M* solution of KH_2PO_4 and 0.05 *M* KH_2PO_4 + 0.02 *M* $CaCl_2$ are given. The pH determinations were made after additions of increasing amounts of a solution of 0.08 *N* NaOH; the readings were taken after 3 hours and after 20 days. In the medium without the calcium the reaction has not changed; in the medium with calcium the reaction after 3 hours is represented by a dotted line, and the reaction after 20 days by a solid line.

If a study is made of this solid line, which corresponds to a condition of equilibrium between the solid and the liquid phase, one may note that the addition of calcium salt to a solution of KH_2PO_4 brings forth two points of buffer activity: 1. Approximately between pH 3.3 and 3.7. 2. Between pH 6.0 and 6.4. An analysis of the first point corresponds to the precipitation of di-calcium phosphate (this may be called the phenomenon of buffer effect of precipitation). The second point of the buffer action corresponds to the inversion of di-calcium phosphate into tri-calcium phosphate (we thus have the buffer effect of the conversion into the solid phase).

TABLE 13

Influence of sprouted corn plants on the solutions of ammonia salts

COMPOSITION OF MEDIUM	REACTION OF ORIGINAL SOLUTION	REACTION AT END OF EXPERIMENT
	pH	*pH*
NH_4NO_3	7.0	3.7
NH_4Cl	6.9	3.7
$NH_4NO_3 + HCl$	4.4	3.8
$H_2O + HCl$	4.4	5.5

TABLE 14

Oat plants grown under daylight conditions

COMPOSITION OF MEDIUM	REACTION OF MEDIUM					
	Before experiment		After 1 hour		After 24 hours	
	a	b	a	b	a	b
	pH	*pH*	*pH*	*pH*	*pH*	*pH*
0.001 *N* $NH_4Cl + HCl$	4.2	4.2	4.4	4.3	3.8	3.8
0.001 *N* $KCl + HCl$	4.2	4.2	4.4	4.2	4.9	5.0
0.001 *N* $MgCl_2 + HCl$	4.2	4.2	5.0	4.9	5.6	5.6
0.001 *N* $CaCl_2 + HCl$	4.2	4.2	4.3	4.5	5.6	5.6

The influence of plants on the solutions of ammonia salts

When it was found that the NH_4NO_3 behaves as a physiologically acid salt, the question came up as to how this property may be changed under the influence of the reaction of the medium. The influence of weak concentrations of HCl on the utilization of ammonium nitrate by plants was therefore tried. Table 13 shows how sprouted corn plants in the experiments of Prianishnikov have shifted the reaction in a solution of ammonia salts during the period of 10 days.

Thus after 10 days of contact with the plants the medium shifted toward the acid side even in the solutions to which an acid was added. Thus the pre-

TABLE 15

The changes in reaction of solutions of NH_4Cl and NH_4NO_3 under the influence of the roots of peas and oats and the absorption of nitrogen from these solutions

EXPERIMENT NUMBER	KIND OF PLANT AND AGE	TIME OF CONTACT OF PLANTS IN SOLUTION CULTURE	COMPOSITION OF MEDIA	BEFORE THE EXPERIMENT	AFTER THE EXPERIMENT	NITROGEN ABSORBED	
		hrs.		*pH*	*pH*	*per cent*	*per cent*
1	Oats, 22 days	2	0.001 N NH_4NO_3	5.8	4.8	5.0	27.9
			0.001 N NH_4NO_3 + HCl	3.7	3.8	38.7	11.5
			0.001 N NH_4Cl	5.9	4.6	...	29.5
			0.001 N NH_4Cl + HCl	3.6	3.7	...	18.8
2	Oats, 13 days	2	0.0005 N NH_4NO_3	5.4	5.4	0	51.6
			0.0005 N NH_4NO_3 + HCl	3.7	4.2	11.5	40.4
			0.0005 N NH_4Cl	5.4	5.3	...	50.2
			0.0005 N NH_4Cl + HCl	3.7	3.7	...	38.4
3	Oats, 13 days	2	0.0005 N NH_4NO_3	5.4	5.4	18.3	51.5
			0.0005 N NH_4NO_3 + HCl	3.7	4.2	37.9	44.6
			0.0005 N NH_4Cl	5.4	5.3	...	50.7
			0.0005 N NH_4Cl + HCl	3.7	4.2	...	52.5
4	Oats, 60 days	3	0.001 N NH_4NO_3	6.1	5.7	34.4	30.0
	Oats, 30 days		0.001 N NH_4NO_3	6.1	6.1	0	31.5
	Oats, 14 days		0.001 N NH_4NO_3	6.1	5.4	25.0	27.1
5	Oats, 74 days	2	0.001 N NH_4NO_3	6.4	6.2	17.2	14.7
	Oats, 44 days		0.001 N NH_4NO_3	6.4	6.6	28.5	32.3
	Oats, 28 days		0.001 N NH_4NO_3	6.4	6.3	0	22.6
	Oats, 14 days		0.001 N NH_4NO_3	6.4	6.2	0	18.3
6	Peas, 20 days	2	0.0003 N NH_4NO_3	5.4	4.8	0	7.7
			0.0003 N NH_4NO_3 + HCl	4.0	4.1	0	0
			0.0003 N NH_4Cl	5.3	4.4	...	11.0
			0.0003 N NH_4Cl + HCl	4.0	4.0	...	0
7	Peas, 20 days	4	0.0003 N NH_4NO_3	5.4	4.8	0	33.7
			0.0003 N NH_4NO_3 + HCl	4.0	6.2	33.6	0
8	Peas, 30 days	3	0.0001 N NH_4NO_3	6.4	5.5	19.3	61.5
			0.0001 N NH_4NO_3 + HCl	5.0	5.3	18.1	54.0
			0.0004 N NH_4NO_3	6.2	5.3	0	23.1
			0.0004 N NH_4NO_3 + HCl	4.9	5.2	0	25.2
9	Peas, 14 days	2	0.0002 N NH_4NO_3	6.4	6.2	0	26.1
			0.0002 N NH_4NO_3 + HCl	3.9	5.8	3.7	0

ponderance of assimilation of ammonia over that of nitrate nitrogen is not dependent on the reaction of the medium.

The foregoing experiment was conducted in the dark. In another experiment conducted under daylight conditions with oat plants which were 25 cm. in length, the results shown in table 14 were obtained.

In this experiment during the first hour there was a tendency to neutralize somewhat the acid solution. After 24 hours, on the other hand, there was a noticeable tendency toward acidifying the solution containing the ammonia salts.

A series of experiments with solutions of NH_4Cl and NH_4NO_3, in which the absorption of NH_4NO_3 and the changes in reaction were determined, was conducted by Domontovitch and Drachev. After the roots have been washed with distilled water the experimental plants grown in complete nutrient solutions were put into the experimental media for a period of 2 to 4 hours. The results are given in table 15.

The data given show that within 2 to 4 hours there was a shift in the reaction toward an increase of acidity in the unacidified solutions of NH_4Cl and NH_4NO_3; in the acidified solutions there was a slight decrease of acidity (0.1 to 0.3 pH). There was a decrease in acidity in the same ratio on both of the media $NH_4Cl + HCl$ and $NH_4NO_3 + HCl$. From equivalent solutions of $NH_4NO_3 + NH_4Cl$ the ammonia was absorbed with the same intensity. In the majority of cases the NH_4 was absorbed faster than the NO_3 in the unacidified NH_4NO_3 solutions. When the NH_4NO_3 solutions were acidified the amount of absorbed nitrate nitrogen increased and the amount of absorbed ammonia nitrogen decreased; however, even on the acidified solutions occasionally the ammonia nitrogen was absorbed more energetically than the nitrate nitrogen.

In general one might say that the physiological acidity in these experiments shows itself clearly on the unacidified solutions; two indications characterize it: 1. The excessive absorption of cations over anions, 2, the shift of the reaction toward an increase of the pH reading of the acidified solutions. On the solutions of $NH_4NO_3 + HCl$ the first indication of physiological acidity infrequently continued to appear although the other at times was obliterated. We may assume (on the strength of the experiments cited above) that with a prolongation of the time of the experiments, there would have been a reverse movement of the reaction toward an increase of acidity, even on the solutions with NH_4NO_3 which were slightly acidified.

The change in reaction of the solution cultures under the influence of the growth of plants in NH_4NO_3 and nutrient media

In nutrient solution cultures with corn various amounts of $NaNO_3$ and NH_4Cl were used. The solutions were not renewed. The changes in reaction are given in table 16. This table shows that the tendency toward acidity becomes noticeable when ammonia nitrogen is substituted for one-fourth of the nitrate nitrogen; under the conditions of the experiment, this combination

appeared to be the optimum, since at a wider ratio the plants suffered from an excess of acidity and on the purely nitrate media the corn plants became strongly chlorotic.

In the experiments in 1924 a comparison was made of the effect of various types of plants on the reaction of the nutrient media, various sources of nitrogen being used in nutrient cultures. The composition of each liter of this solution for both media as well as the nitrogen source was as follows: KCl—0.03 gm.,

TABLE 16

The influence of the ratio NO_3:NH_4 on the change of reaction in solution cultures with corn

NO_3:NH_4 IN EQUIVALENTS	TIME PERIOD IN DAYS								
	Start	7	10	14	20	28	37	45	54
	pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
1:0	4.7	5.4	5.6	5.7	5.9	6.0	5.9	6.0	6.3
¾:¼	4.7	4.5	4.3	4.2	3.9	4.1	4.5	4.7	4.0
½:½	4.7	4.5	4.3	4.1	3.8	3.5	3.4	3.5	3.4
¼:¾	4.7	4.5	4.3	4.1	3.7	3.4	3.4	3.0	3.0
0:1	4.7	4.3	3.9	3.6	3.4	3.2	3.0	2.8	2.8

TABLE 17

The change of reaction during the growth period of the plants in solution cultures on a complete medium containing various sources of nitrogen

NUMBER OF DAYS	$NaNO_3$						NH_4NO_3						NH_4Cl					
	Oats	Corn	Peas	Clover	Beans	Buckwheat	Oats	Corn	Peas	Clover	Beans	Buckwheat	Oats	Corn	Peas	Clover	Beans	Buckwheat
	pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
0	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
5	...	6.3	...	5.5	5.5	...	...	4.2	...	5.2	5.5	...	...	3.6	...	5.1	4.1	...
8	6.1	6.3	5.7	...	...	...	5.3	3.8	4.5	...	...	...	4.5	3.1	4.4	...	...	...
11	6.5	...	6.5	...	...	5.6	4.9	...	4.3	...	...	5.0	3.7	...	3.9	...	...	4.5
16	7.3	6.8	7.2	6.5	6.2	5.6	4.0	3.3	4.5	4.0	4.2	4.3	3.3	2.9	4.0	3.7	3.7	4.0
20	7.4	...	7.2	6.6	6.3	5.7	3.9	...	4.2	4.0	3.9	4.0	3.3	...	3.9	3.7	3.6	3.6
28	...	6.9	...	7.0	6.9	5.8	...	3.4	...	3.9	3.6	3.6	...	2.9	...	3.7	3.6	3.5

KH_2PO_4—0.06 gm., $MgSO_4$—0.06 gm., $CaCl_2$—0.08 gm., $CaSO_4$—0.12 gm., Fe—0.05 mgm. (tartarate). As for the nitrogen source in medium 1 there was $NaNO_3$—0.26 gm.; in medium 2, NH_4NO_3—0.12 gm.; in medium 3, NH_4Cl—0.16 gm.

Three plants were put into each vessel of 1.8 liter capacity. The contents of the vessels were stirred every half hour. The results of the experiment are given in table 17.

From the observations on the growth of the plants, the following was noted:

On the NH_4Cl medium the grain crops and legumes were killed. The leaves dried up or dropped off. The killing of legumes (peas, clover, beans) took place at pH 3.9 to 3.6; oats died at pH 3.3; and corn at pH 3.1 to 2.9; the buckwheat was an exception. This survived, and at the end of the experiment the reaction of the medium was 3.5. Although the plants were stunted they remained alive and to all appearances seemed to be healthy. On the NH_4NO_3 medium the beans and clover seem to have suffered most; the peas looked better; the other plants maintained their normal appearance; on the corn, notwithstanding the 13 days of contact with the solution of pH 3.3 to 3.4, only the tips of the roots appeared to die off. On the $NaNO_3$ medium the plants were healthy except for the beans and clover, which wilted toward the end of the experiment. If attention is directed to the general character of the change in reaction of the solution and especially to the direction of the change, the conclusion may be drawn that in the experiments described, all types of plants in general have shown analogous influence on the reaction. There were no sharply defined qualitative differences among the plants used in the experiment.

On the NH_4Cl media the plants lowered the pH of the solution somewhat faster, bringing about the point of toxic limit after 15 or 20 days. On the NH_4NO_3 media there was a slow and gradual approach to this limit accompanied by a greater or less depression of growth. In the nitrate media the reaction approached the narrow interval of reaction around the neutral point.

TABLE 18

The change of reaction during the growth period of wheat and buckwheat grown on nitrate media

PLANTS	SOURCE OF P_2O_5	BEGINNING	AFTER 20 DAYS	AFTER 30 DAYS
		pH	*pH*	*pH*
Wheat	KH_2PO_4	4.1	6.4	...
Buckwheat	KH_2PO_4	4.1	5.6	5.8
Buckwheat	Saratov phosphate	5.5	5.9	6.0
Buckwheat	Without phosphate	4.1	4.1	4.4

There were quantitative differences in the speed of change of reaction among the individual plants; these differences are not accidental in the experiment; they are characteristic for the particular species.

The higher limit of reaction for oats and corn on the media with ammonium chloride as compared with the legumes may be ascribed to the sensitiveness of the legumes to an acid reaction. The absence of killing effects on buckwheat in the NH_4Cl medium may be explained by the ability of this plant to withstand a wide range of reaction after which a depression of the growth takes place; only after this limit is a killing reaction possible for buckwheat. If the variations in pH for the ammonium nitrate and the ammonium chloride media are noted, after the twentieth day the following is apparent: For oats, pH 0.6; corn—0.4; buckwheat—0.4; peas—0.3; clover—0.3; beans—0.3. The figures for the various plants (except oats) are very similar. On the neu-

tral medium one property is outstanding; namely, the appreciable constancy of the reaction in the vessels with buckwheat. The tendency to approach the neutral point was apparent up to end of the experiment. In another experiment where only nitrate media were used the results shown in table 18 were obtained.

In this case, therefore, the weakly acid reaction of the nitrate medium became more constant under buckwheat than under wheat (notwithstanding the weak development of the wheat). On the phosphates (Saratov) the development of buckwheat was just as successful as on the KH_2PO_4; therefore the (Saratov) phosphate was assimilated by the buckwheat at a reaction of the medium ranging between pH 5.5 and 6.0.

SUMMARY

Part I

The NH_4NO_3 nutrient medium proposed by Prianishnikov on the basis of his experiments with sand cultures during 1900–1901 gave results close to those obtained with the Hellriegel medium; with certain plants (like water cress and flax) the medium gave even better results, but with others (like lupines and peas) it gave poorer results than with the Hellriegel medium.

The cause of these differences may be looked for in the following conditions:

The earlier assumption that the reaction of this medium, which is close to neutrality will not shift either way on account of the buffer action of the di-calcium phosphate, did not materialize. Further experiments have shown that the physiological acidity of ammonium nitrate is a great deal stronger than was thought in the beginning; the acidity may approach a point comparable to that produced by the presence of ammonium chloride. Thus although in the Hellriegel medium there is a shift of the reaction from acidity to neutrality, in the Prianishnikov the reverse is true. Since various plants on one hand tolerate differently shiftings of the reaction and on the other hand have a different power of producing changes in reaction, the results of applying one or the other media are subject to change under the influence of the type of plant.

Besides, it was observed that the Prianishnikov medium infrequently gave poorer results in nutrient solution cultures than in sand cultures. The causes of differences between the nutrient solution cultures and the sand cultures may be ascribed to the possible buffer action of the impurities found in sand; it may also be caused by the unequal distribution of the NH_4NO_3 and $Ca_2H_2(PO_4)_2$ in the vertical column of the nutrient cultures as compared with the sand cultures. For this reason the physiological acidity of the ammonium nitrate is not neutralized by the action of the di-calcium phosphate, which is found as a precipitate on the bottom of the vessel. The stirring of the solution at 24-hour intervals is not sufficient to prevent the acidity produced around the roots from doing the damage. In view of the above, the solution cultures for the best results ought to have such a modification of the nutrients that the ratio of nitrate nitrogen to ammonia nitrogen would be more than unity.

Among other media which were studied, the one of Crone with slight modifications was successful; the changes produced consist in replacing the $Fe_3(PO_4)_2$ with $Fe_2(SO_4)_3$ with a corresponding increase in the amount of $Ca_3(PO_4)_2$.

Part II

The experimental part of this paper deals with a detailed study of the mutual influence of the different ingredients of the Prianishnikov medium; the primary thought was to reduce the physiological acidity of NH_4NO_3 by the buffer activity of $Ca_2H_2(PO_4)_2$.

The titration curves of the Hellriegel and Prianishnikov media show the greatest buffer activity at a pH close to neutrality. The buffer action depends not only on the conversion of the phosphates, $HPO_4'' + H' \leftrightarrows H_2PO_4'$ in the solution, but also on the precipitation or solubility of the calcium phosphate.

To illustrate the buffer effect of precipitation of phosphates of calcium and the buffer effect of the conversion of the solid phase ($2CaHPO_4 + Ca \leftrightarrows Ca_3(PO_4)_2 + 2H$), the titration curves of KH_2PO_4 and $KH_2PO_4 + CaCl_2$ are given.

In a series of experiments of short duration on the absorption of NH_4 and NO_3 by the plants from solution—either from NH_4NO_3 alone, from ammonium chloride, or from a weakly acid solution of $NH_4NO_3 + HCl$ or $NH_4Cl + HCl$—the characteristic physiological acidity of NH_4NO_3 was noticed. This was expressed by the following: 1. A more speedy absorption of NH_4 than NO_3. 2. The shifting of the reaction toward an increase of acidity on the unacidified solutions. On the acidified solutions (up to a pH 4.0) the first symptom of physiological acidity of NH_4NO_3 infrequently was noticed, although in a slightly less degree than when a neutral reaction was maintained in the beginning. However, the second indication—the increase of acidity—on cultures already acid from the start; in experiments of short duration, was not observed. It is possible that this is due to the speedy absorption by the plants of the free acid added to the medium. On the medium with NH_4Cl and HCl and with a pH of 4.0, there was a noticeable shift toward alkalinity after 1 hour, followed by an acidifying tendency after 24 hours.

The influence of the various plants on the reaction of a complete medium containing $NaNO_3$, NH_4NO_3, or NH_4Cl, with a small amount of KH_2PO_4 was qualitatively somewhat similar. On the nitrate media the general tendency for all plants was to neutralize the original acidity of the solution (pH 5.5); it was, however, not so pronounced with the buckwheat. Legumes were successful in bringing about a reaction with ammonium chloride to pH 3.9–3.6, at which point they died; the grain crops, like oats and corn, brought the acidity down to 3.3–2.9.

The buckwheat tolerated the acidity produced with the ammonium chloride to a greater extent than all the other plants.

For all plants the difference in pH for the media with ammonium nitrate and in mixtures with ammonium chloride was not great—pH 0.3–0.5—within a

period of 3 weeks experimentation. The injurious influences on the first medium appear later and with less rapidity than on the other media.

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SOME COMPARISONS OF THE PROPERTIES OF HUMID-TROPICAL AND HUMID-TEMPERATE AMERICAN SOILS; WITH SPECIAL REFERENCE TO INDICATED RELATIONS BETWEEN CHEMICAL COMPOSITION AND PHYSICAL PROPERTIES

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In the course of a recent reconnoissance of Central American soils two quite distinct classes of upland clays were encountered. The types comprising one class are friable, freely permeable to water, resistant to erosion, and often show faint profile zonation; whereas the types comprising the other class generally are plastic or stiff, much more impervious, and show better profile zonation. The older concept that the physical properties of soils are largely the resultant of the varying percentages of sand, silt, and clay would not explain the different behaviors of these two classes of soils, since a number of the types of essentially the same texture have shown opposite physical properties. Some of them, although containing an extremely small amount of gritty material, are as friable as light sandy loam, whereas others of similar texture are very stiff.

This paper correlates the friability and plasticity of certain heavy clay soils as determined by field methods with the $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ ratio of the same soils obtained by chemical analyses made in the laboratories of the Bureau of Soils.

The analytical results cited show the composition of the whole soil and not that of the colloidal constituent alone, but since these soils are very heavy and undoubtedly high in colloidal content, it is believed that the results may be accepted for the purposes of this paper as essentially equivalent to the results that would be obtained by separating and analyzing the contained colloids.

It has been found that the colloidal materials extracted from different soils vary widely in their chemical compositions (14) and in their physical properties (1, 6, 13). Moreover, it appears from recent work (2) that the physical properties of the colloidal material are fairly well correlated with the chemical composition, as expressed by the molecular ratio $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$.

SOME RELATED INVESTIGATIONS AS RECORDED IN THE LITERATURE

Van Bemmelen (15, 16) considers the end-product of lateritic weathering as silica-free alumina; but states that the agents and conditions which cause lateritization, whereby the ratio of silica to alumina is lowered to 1:3 to 1:0,

in contradistinction to ordinary weathering, are not understood. He observes that ordinary and lateritic weathering go on together in some regions, that the former never goes over into the latter under certain conditions and climates, whereas under still other conditions it goes over wholly or in part. He further observes that the heavy clay soils of Holland with a silica : alumina ratio of over 2 are highly plastic, whereas the lateritic clays of Java with a silica : alumina ratio approaching 0 have no plasticity.

Hardy in studying the significance of the shrinkage coefficient of "clays and soils" (7) ascribes the high ratio of Al_2O_3 plus Fe_2O_3 to SiO_2 for certain red soils from Dominica and Barbados to their "lateritic nature," and observes that these types probably owe their special physical characters mainly to the presence of colloidal aluminum hydroxide. He further states that the low ratio of Al_2O_3 plus Fe_2O_3 to SiO_2 for certain types from Montserrat and Antigua indicates that the colloidal material in these types resembles more that contained in soils of temperate regions. He concludes that red lateritic soils, rich in alumina hydrogel, appear to possess relatively low vesicular water contents, and, in consequence, to exhibit low shrinkage coefficients. He believes that the colloidal matter of soils of different origin and chemical composition is specific in certain of its properties and that many of the apparent anomalies in the behavior of soils may be satisfactorily explained by differences in the physical constants in the colloids. From his research on the maximum water-retaining capacity of "colloidal soils" (8) he finds that West Indian "red lateritic soils," whose colloidal content is described as being composed mainly of the hydrogels of alumina and of ferric oxide, exhibit remarkably low volume expansion on wetting.

Joseph (9) finds a certain correlation between the imbibitional water-holding capacity of a number of Sudan clay soils and their chemical composition. Red soil with a silica : alumina ratio of 2.85 showed a very much lower capacity in this respect than the other types, which consist of brown alluvial, brown loessial, and blue loessial types, with silica : alumina ratios ranging from 3.77 to 4.77. He found the plasticity of the colloids in "slate-blue clay" from the upper Nile very high and that of the colloids taken out of red subsoil from Mongalla, very low. In his work on a number of tropical and temporate zone clays he points out (10) an important characteristic in the silica : alumina ratio of the clay separates, noting that this ratio seems connected with essential "clay" properties, being low in non-plastic and high in plastic materials.

It is said to be common knowledge among the Hawaiian sugar plantation operators that Hawaiian clays have radically different physical properties from those of England and the United States—that they do not scour the moldboard of plows well and are generally friable under all conditions. Maxwell's investigations on Hawaiian soils (11) show that most of the soils are low in silica and high in iron and alumina, the average molecular ratio of silica to iron plus alumina being about 0.9.

PROPERTIES OF CENTRAL AMERICAN SOILS

Large areas of well-drained upland soils occurring in the humid parts of Central America have a much higher content of clay and show much greater friability than commonly characterize the finest textured upland types of humid United States. This is true even for many tropical areas having predominantly sloping topography. Presumably the soil of these sloping situations has not lain undisturbed long enough to have had exerted upon it the fullest possible effect of oxidation, hydration, and leaching, such as might be expected on uneroded flats. Wherever erosion has kept such close pace upon rock decay that incompletely decomposed fragments of the parent material are fairly abundant at shallow depths the condition generally may be construed as reflecting a stage of weathering somewhere short of mature soil development. This view may need modification in some instances, as for example, where particles and fragments of highly resistant rocks, such as quartz and agate, are present in considerable amounts through the soil profile.

Notwithstanding the usual sloping features of the region and the more or less conformity as regards soil immaturity in some situations, the products of weathering, in case of the clay types in particular, are profoundly different over extensive areas from those of similar texture usually found in like positions in the wet temperate zone, taking the United States as a representative region for comparison. In this part of the tropics the soils either have undergone more intense weathering or they have undergone changes unlike or partly unlike those that have taken place under average conditions at the more northerly latitudes. The influence of the parent rocks often can not be seen in anything like the same degree encountered in the hilly parts of humid United States, although close relation does exist locally between parent rock and derivative soil, as will be pointed out below.

With a constantly warm temperature and long periods of heavy rainfall, weathering in the tropics has had a much stronger leveling effect upon soil character in this region; rocks have decomposed to greater depths and much more completely in that part of the profile above the zone of visible continuing decay; clays of marked uniformity have developed over large areas and have become exceedingly fine grained; exceptional friability and permeability have resulted; and susceptibility to erosion has been greatly minimized. Soils of clay texture are largely in the predominance over the uplands, except in the vicinity of active or recently active volcanoes. Clays seem to be the normal regional soils, as much so as sandy types are the usual soils found in the coastal plain of southeastern United States.

In extensive areas from Guatemala to Colombia the soil consists of red, buff, and ocherous-yellow (mostly red) clay, showing frequently no conspicuous physical difference from place to place, except that some areas are more friable than others, even though there is wide variety in the underlying rocks, including the basic igneous group and the sedimentaries, such as limestone, shale, and

claystone. It is not meant that there are not widely different soil types within the region. Actually there are a considerable number of variations, but many of these owe their peculiarities to such obvious local conditions as immaturity of weathering, imperfect drainage and, in the more eroded situations, to the lithologic nature of the parent material. As a rule quartz or other gritty particles can not be detected in the clay soil referred to by ordinary field examination, or only small amounts can be found; but in those localities where granitic rocks and the mica schists are abundant, as in northern Honduras, fragments and particles of quartz and flakes of mica are fairly common in the shallow soils. In the latter types comparisons of the ratio of silica to iron plus alumina can not be made properly in all instances with the corresponding ratios for the clays containing little or none of these larger mineral fragments. Some of the physical variations referred to have a pronounced tendency, with advanced weathering, in the direction of:

(*a*) Greater friability and permeability than is commonly found in fine-textured soils of similar origin in the temperate zone, as already pointed out; (*b*) the development of uniform red, yellow, and buff colors; and (*c*) exceptional profile uniformity.

Similarly the chemical-variations show a tendency under advanced weathering toward an end product having relatively low contents of silica and of the bases, CaO, MgO, Na_2O, and K_2O, and comparatively high contents of iron and alumina. This refers to the well-drained older types.

A striking difference from humid temperate-zone soil conditions is seen in the frequent faint development in the direction of sharply differentiated soil layers or horizons through the vertical section, even where the soil is deep. As a rule the dominant soils, the red clays, have

(*a*) A surface layer, ranging from about ½ to 3 or 4 inches in thickness, in which organic matter from vegetation has slightly darkened the red soil, although there are places where scarcely any top soil of this kind is observable. Beneath this faintly developed surficial zone is found (*b*) red clay which is essentially uniform to depths ranging from about 2 to 8 feet; at which point the clay (*c*) is often splotched or streaked with material of yellowish, bluish-gray, and whitish or cream colors, often accompanied by soft partly decayed rock material.

There are in these red clays generally no important textural differences between a and b, and often very little or none between a, b and c; and the divisional lines are rarely sharp, the material of one section grading into that of another. Frequently the light and yellowish streaking and mottling of section c represents freshly decayed or partly decayed rock materials of varying character, in which oxidation, leaching, etc. have not advanced to the same stage as in the red soil above. The soil of section c really represents, in a great many instances, what might be designated a secondary or tertiary product of weathering from the parent rock, in that the primary product of weathering usually shows less complete obliteration of the granular character of freshly disintegrated rock. Sections a and b, in other words, represent more nearly

the true soil in the sense of thorough decomposition of practically all of the parent rock material.

This faint zonation or lack of development of obvious horizons through the profile is a common characteristic of large areas of soil not only in Central America but also in parts of the West Indies and northern South America. This seemingly is due, in part at least, to a weakened efficiency in processes of elutriation and eluviation resulting from the peculiar nature of the fine particles formed under wet tropical conditions, a considerable proportion of which has been found to be of a colloidal nature. That the fine material clings together to form clusters from which the individual grains are not readily detached by water to become suspended and moved through the soil mass is evidenced by the physical properties of the soils, such as a highly permeable or granular structure through which water passes rapidly; and the usual rapidity with which the material, when suspended in water by violent agitation, falls out of suspension.[1] Thus there is little opportunity for concentration of clay in the sublayers to form zones of heavier texture than those above, from which the finer particles under dissimilar climatic conditions might have been moved downward by percolating water. In the absence of strongly effective elutriation and eluviation the comparatively coarser textured surface soils so common to humid temperate regions fail to develop over much of the country under discussion; and without effective processes of this nature there would seem to be *a priori* no possibility of developing heavier sublayers, such as are also common to many areas of smooth topography in the temperate zone, except as they are formed through decay of parent material that weathers directly into soil of fine texture.

The content of flocculent colloidal material of the kind referred to is prevailingly higher in some parts of the humid American tropics than in others. This appears to be due partly to an exceptionally heavy rainfall and good under drainage, and partly to the character of the parent material.

In the very humid eastern part of Costa Rica there is considerable soil so open natured by reason of the aggregated or flocculated fine material that rain water rapidly passes into and through the ground, and the soil exhibits such slight stickiness that the land can be plowed during or immediately after a heavy rain to form a very granular tilth (plate 1).

This Costa Rican type—Columbiana clay (tables 1 and 5)—is of exceedingly fine texture, containing only 0.7 per cent of particles coarser than silt; yet it is as friable as the mellowest loam, and in the practical sense is not susceptible to erosion (3, 4). It is derived from old outwash material coming from basic igneous rocks and volcanic ejecta on the slopes of the adjacent cordillera. In this region the rainfall is very heavy—209 inches at Sarapaquí.

[1] Colloid extracted from a sample of extremely friable tropical soils of clay texture from Costa Rica has exhibited considerable immunity from miscibility with water, requiring intimate rubbing of the material to bring about dispersion. The material falls out of suspension quickly.

TABLE 1

Chemical analyses of friable tropical soils

TYPE AND COUNTRY	SAMPLE NUMBER	DEPTH	SiO_2	TiO_2	Fe_2O_3	Al_2O_3	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	N	CO_2 FROM CARBONATES	IGNITION LOSS	ORGANIC MATTER	MOLS $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$
		inches	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	
Espiritu Santo clay, Honduras	28126	24–36	41.87	0.69	6.19	32.53	0.04	0.14	0.18	0.71	0.28	0.24	0.09	0	15.63	.....	1.90
Arraiján clay, Panama	30514	0–3	34.57	1.67	16.13	25.73	0.36	0.38	0.72	0.09	0.07	0.12	0.39	0	20.39	.....	1.60
	30515	3–30	38.13	1.37	14.59	31.47	0.24	Tr.	0.71	0.14	0.02	0.07	0.09	0	13.25	.....	1.60
	30516	30–40	40.48	1.28	14.53	30.25	0.15	Tr.	1.62	0.35	0.04	0.02	0.03	0	10.98	.....	1.70
	30517	40–52	41.08	1.23	15.66	30.97	0.12	Tr.	0.93	0.70	0.32	0.02	0.02	0	9.04	.....	1.70
Turrialbas silty clay, Costa Rica	30557	0–14	33.85	2.02	11.64	33.78	0.08	0.32	0.22	0.26	0.39	0.56	0.19	0	17.07	.....	1.40
	30558	14–32	30.28	2.37	16.13	34.02	0.12	0.23	0.32	0.19	0.38	0.54	0.09	0	15.88	.....	1.10
	30559	32–60	28.99	2.51	16.83	33.79	0.22	0.32	0.42	0.25	0.41	0.51	0.08	0	15.54	.....	1.10
	30560	60–90	30.63	2.55	16.77	34.33	0.19	0.32	0.32	0.28	0.52	0.48	0.07	0	14.43	.....	1.20
Aragon clay, Costa Rica	30567	0–11	28.65	2.06	13.20	33.79	0.07	Tr.	0.08	0.15	Tr.	0.19	0.26	0	21.81	7.21	1.10
	30568	11–20	30.04	1.89	12.93	34.79	0.04	0.10	0.28	0.25	0.27	0.32	0.15	0	18.95	3.45	1.20
	30569	20–40	30.40	1.99	13.82	35.79	0.04	0.10	0.13	0.19	0.18	0.31	0.07	0	17.62	1.83	1.15
	30570	40–96	26.49	1.99	14.44	38.16	0.03	0.10	0.15	0.17	0.20	0.32	0.04	0	17.82	0.59	0.90
	30571	96–132	24.57	2.21	14.78	38.88	0.03	0.10	0.19	0.19	0.15	0.32	0.04	0	18.45	0.85	0.85
	30572	132–144	25.25	2.08	14.10	39.05	0.03	0.10	0.17	0.23	0.13	0.35	0.04	0	18.32	0.67	0.90
	30573	144–162	9.77	2.13	16.95	45.98	0.03	0.10	0.18	0.14	0.12	0.48	0.02	0	25.00	0.71	0.30
	30574	162–202	5.00	2.62	19.31	46.89	0.18	Tr.	0.20	0.05	0.05	0.56	0	0	25.14	0.47	0.15
	30575	at 35 ft.	38.21	2.08	14.08	32.00	0.29	Tr.	0.20	0.10	Tr.	0.28	0.003	0	12.69	.....	1.60

Columbiana Clay, Costa Rica	30584	0–24	18.79	2.37	16.30	38.48	0.34	Tr.	0.37	0.23	0.09	0.40	0.17	0	22.52	3.82	0.65
	30585	24–65	17.92	2.22	14.52	37.34	0.23	Tr.	0.37	0.23	0.09	0.48	0.13	0	26.48	7.76	0.65
	30586	65–108	26.77	2.06	16.01	34.66	0.37	1.37	3.06	0.14	0.17	0.59	0.01	0	14.92	.....	1.00
Uruca loam, (Sub.), Costa Rica	30608	92–102	40.33	1.21	12.02	27.15	0.16	1.62	3.64	0.36	0.58	0.24	0.03	0	11.97	.....	1.96
Cukra clay, Nicaragua	30644	0–7	29.64	3.74	17.05	25.00	0.20	0.31	0.29	0.25	0.23	0.55	0.43	0	22.10	.....	1.90
	30645	7–60	31.57	2.94	19.83	28.00	0.14	0.27	0.22	0.24	0.21	0.52	0.12	0	16.50	.....	1.30
Average	.....	....	29.30	....	14.91	34.28	....	0.24	0.62	0.25	0.21	...	.....	.....	.....	.....	1.25

TABLE 2

Chemical analyses of non-friable tropical soils

TYPE AND COUNTRY	SAMPLE NUMBER	DEPTH	SiO_2	TiO_2	Fe_2O_3	Al_2O_3	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	N	CO_2 FROM CARBONATES	IGNITION LOSS	ORGANIC MATTER	MOLS $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
		inches	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	
Lancatillal clay loam, near Guatemala, Honduras boundary	28109	0–8	44.40	1.56	10.89	20.89	0.09	6.17	5.80	0.66	1.55	0.13	0.27	.....	9.30	4.01	2.00
	28110	8–18	45.83	1.57	12.15	20.53	0.09	6.07	5.78	0.74	1.35	0.10	0.08	.....	5.48	.....	2.50
La Francia clay, Honduras	28111	0–2	57.59	0.81	5.77	17.26	0.04	0.74	0.70	1.89	0.41	0.12	0.46	.....	13.57	6.73	4.60
	28112	2–36	62.06	0.75	5.95	18.80	0.05	0.45	0.65	1.75	0.43	0.14	0.22	.....	8.57	3.35	4.60
Talladega clay, Honduras	28123	0–3	65.00	0.74	4.47	14.48	0.29	0.32	0.43	1.38	1.24	0.06	0.17	.....	11.22	5.92	4.60
	28124	3–20	62.77	0.72	5.98	19.88	0.08	0.15	0.44	1.91	1.24	0.04	0.05	.....	6.33	1.50	4.50
Tosentales clay, Honduras	28148	0–36	67.00	0.53	2.77	12.25	0.04	6.97	1.85	2.85	1.27	0.06	0.03	.....	4.36	2.36	8.10
Chandler loam, Honduras	28154	6–36	77.00	0.76	2.43	9.75	0.04	1.06	0.63	1.76	1.00	0.06	0.14	.....	5.90	.....	11.60
Santa Rosa clay, Panama	30522	0–6	47.48	0.95	10.67	17.04	0.17	1.98	1.97	0.32	0.13	0.14	0.66	0	19.30	.....	3.40
	30523	6–22	49.49	1.06	11.85	19.25	0.18	1.93	2.23	0.28	0.11	0.10	0.33	0	13.78	.....	3.10
Uruca clay loam, Costa Rica	30533	0–9	41.27	1.67	11.87	25.89	0.14	2.50	1.11	0.76	1.45	0.26	0.15	0	13.65	.....	2.10
	30534	9–13	41.37	1.68	13.53	26.31	0.19	1.66	0.59	0.71	1.20	0.25	0.11	0	12.33	.....	2.00
	30535	13–40	42.40	1.86	13.39	27.60	0.16	0.99	0.46	0.73	0.96	0.21	0.05	0	11.64	.....	2.09
	30356	40–47	44.20	1.39	11.55	28.40	0.17	0.81	0.88	0.48	0.81	0.14	0.03	0	11.65	.....	2.10
Aragon clay, Costa Rica	30576	at37 ft.	43.51	1.03	7.13	27.85	0.17	0.79	1.27	2.10	1.35	0.46	0	0	9.31	.....	2.50

Bluefields clay, Nicaragua	30653	0–8	59.01	1.86	7.18	14.59	0.04	0.37	0.54	0.29	0.25	0.08	0.26	0	15.24	.....	5.20
	30654	8–40	47.78	1.24	10.24	25.39	0.01	0.29	0.67	0.50	0.24	0.04	0.08	0	13.20	.....	4.00
	30655	4–120	48.57	1.42	13.55	23.93	0.02	0.25	0.88	0.81	0.23	0.06	0.02	0	9.88	.....	2.50
Vinces clay, Ecuador	31222	0–14	48.57	1.31	11.34	24.20	0.26	0.72	0.63	0.37	0.41	0.13	0.14	0	11.95	2.60	2.60
	31223	14–42	46.38	0.99	10.46	29.03	0.05	0.18	0.70	0.16	0.11	Tr.	0.05	0	12.18	0.50	2.20
	31224	42–120	48.91	1.11	10.37	27.23	0.02	0.15	0.77	0.17	0.12	0.04	0.02	0	11.34	0.22	2.40
	31225	120–160	52.32	0.96	10.26	23.80	0.22	0.32	1.23	0.40	1.07	0.04	0.001	0	9.29	0.37	2.90
San Pablo clay, Canal Zone	31355	0–7	58.35	1.56	12.37	13.67	0.24	0.62	0.51	0.28	0.36	0.08	0.29	0	12.31	4.55	4.60
	31356	7–48	49.50	1.34	12.56	22.59	0.05	2.41	0.92	0.32	0.26	Tr.	0.03	0.82	10.17	1.46	2.80
Average	......	....	52.33	....	9.53	21.28	....	1.55	1.32	0.90	0.73	....	.....	.....	.....	.....	3.71

TABLE 3

and range of silica, iron and alumina, total bases, and molecular ratio of silica to iron and alumina in 24 friable and non-friable soils

	AVERAGE SiO_2	RANGE SiO_2	AVERAGE $Fe_2O_3 + Al_2O_3$	RANGE $Fe_2O_3 + Al_2O_3$	AVERAGE $CaO + MgO + K_2O + Na_2O$	RANGE $CaO + MgO + K_2O + Na_2O$	AVERAGE MOLS $\frac{SiO_2}{Fe_2O_3 + Al_2O_3}$	RANGE MOLS $\frac{SiO_2}{Fe_2O_3 + Al_2O_3}$
Friable.....	29.30	5.00–41.87	49.19	31.19–66.72	1.32	0.13– 6.55	1.25	0.15– 1.96
Non-friable.	52.33	41.27–77.00	30.81	12.18–38.78	4.50	0.85–17.17	3.71	2.00–11.6

TABLE 4

Physical composition

FRIABLE GROUP				NON-FRIABLE GROUP			
Sample number	Sands and fine gravel	Silt, clay and colloids	Colloids by absorption	Sample number	Sands and fine gravel	Silt, clay and colloids	Colloids by absorption
	per cent	*per cent*	*per cent*		*per cent*	*per cent*	*per cent*
28126	23.1	76.9	....	28109	53.3	46.7	....
30514	1.5	98.5	66.5	28110	64.7	35.3	....
30515	0.7	99.3	82.0	28111	14.7	85.3	....
30516	0.5	99.5	91.0	28112	11.7	88.3	....
30517	0.6	99.4	86.0	28123	26.4	73.6	....
30557	1.3	98.7	64.7	28124	21.1	78.9	....
30558	3.1	96.9	61.2	28148	19.5	80.5	....
30559	4.4	95.6	59.5	28154	48.0	52.0	....
30560	6.0	94.0	58.3	30522	4.9	95.1	90.4
30567	2.9	97.1	75.4	30523	7.3	92.7	90?
30568	2.5	97.5	77.3	30533	17.1	82.9	67.2
30569	1.1	98.9	80.3	30534	5.6	94.4	74.5
30570	1.6	98.4	81.3	30535	5.0	95.0	83.2
30571	1.2	98.8	86.1	30536	7.8	92.2	71.0
.....	....	....	....	30576	....	....	....
30572	1.7	98.3	87.2	30653	8.0	92.0	55.0
30573	2.4	97.6	49.7	30654	2.6	97.4	82.1
30574	4.3	95.7	36.6	30655	1.2	98.8	66.0
30575	4.4	95.6	41.7	31222	6.3	93.7	56.2
30584	0.7	99.3	71.0	31223	2.8	97.2	74.8
30585	1.2	98.8	66.9	31224	3.0	97.0	67.3
30586	4.9	95.1	90.5	31225	4.6	95.4	68.6
30608	22.6	77.4	75?	31355	....	....	....
30644	5.5	94.5	79.9	31356	....	....	....
30645	4.9	95.1	87.6	.....	....	....	....
Average..........		....	71.9	.....	....	....	72.7

Another very friable clay found near Turrialba in eastern Costa Rica—Aragon clay (tables 1 and 5)—although showing no important textural differ-

entiation throughout that part of the profile above the section containing a small amount of incompletely decomposed rock particles, beginning at 13½ feet (table 4), does show some color zonation (table 5). In this type it will be observed that there have been considerable reduction in the amount of silica present and an increase of alumina and iron from the surface down into the horizon containing partly decomposed rock particles (table 4). Within a depth of 13½ feet the diminution of silica has been from approximately 30 per cent to 5 per cent (table 1); and the increase of alumina and of iron (Fe_2O_3) from 34 to 47 and from 13 to 19 per cent, respectively. The bases (CaO, MgO, K_2O, and Na_2O) have decreased from an average of 0.6 per cent in the surface 40 inches, to 0.3 per cent; phosphorous (P_2O_5) has increased from 0.19 to 56 per cent; and organic matter has decreased from 7.2 to 0.47 per cent.

DEGREE OF WEATHERING

This type of weathering indicates that silica leaches from some land areas at a relatively faster rate than iron and alumina.[2]

Weathering activities of the nature described above seem to be responsible for the development of the peculiar soil conditions found in these regions, and this type or *degree of weathering* undoubtedly accounts for the abundance of soils in the humid tropics, which have been described as laterites or as being lateritic.

Clarke says in this connection (5, p. 488–490):

> In tropical and subtropical regions the processes of rock decay are often carried further than is usually the case within the temperate zones. The leaching is more complete, the silicates are more thoroughly decomposed, and the residues are richer in hydroxides. In India, for example, large areas are covered by a red earth known as laterite, which in some cases is undoubtedly a derivative in place of preexisting rocks, such as granite gneiss, basalt or diorite. In other cases the laterite is detrital in character and far distant from its place of origin. The term has been vaguely used, and as employed by different writers it has meant very different things. It has been applied to ferruginous clays, sediments, beds of iron ore, and products of volcanic action, and its formation has been attributed to a variety of causes

[2] Clarke's data (5, p. 115) seem to show that the rivers of North America carry to the sea about 13 times as much silica as iron and alumina, whereas the lithosphere contains somewhat less than 3 times as much silica as iron and alumina. As to what degree these results may need to be modified by possible failures to measure the amount of various constituents carried in colloidal suspension (17) is not known.

Some soils show under the microscope the presence of secondary quartz. This is true of the highly quartzose soil occurring in the sandy savanas of Northeastern Nicaragua (determined by W. H. Fry, Bureau of Soils). Just what conditions are most favorable to leaching out of silica and to development of secondary quartz, and as to what the quantitative relation is between removal and accumulation of this material, are facts which are probably unknown. Merrill has pointed out (12) that in certain rocks, such as the siliceous crystallines, diorite, and some of the diabases, iron and alumina are less subject to removal by leaching than silica.

It has been shown that soil colloids of dry regions are higher in silica than the colloids of wet-region soils (14).

. . . . whatever its derivation . . . . true laterite is essentially a mixture of ferric hydroxide, aluminum hydroxide and free silica in varying proportions. To laterite in situ this statement applies very closely; detrital laterite is usually contaminated by admixtures of clay. Just as in the formation of kaolin, the process of lateritization may be complete or partial; the typical product appears only when the alteration of the parent rock has gone on to the end. Then the silicates seem to be completely broken down, whereas in kaolinization a stable, hydrous silicate remains. A careful reduction of the data leads to the supposition that the residual substance is a mixture of gibbsite, AlO_3H_3; diaspore, AlO_2H; and limonite, $Fe_4H_6O_9$. In short, laterite is identical in type with bauxite, and is merely an iron-rich variety of the latter. Between aluminous beauxite and the iron compound limonite all sorts of mixtures may occur.

There is much in the literature that relates to lateritic soils, but a discussion of this is not deemed pertinent to this paper which does not propose to define lateritic soils, although dealing with material some of which appears to correspond closely with soils that some investigators have described as being lateritic.

SIGNIFICANCE OF THE SILICA: IRON PLUS ALUMINA RATIO

If the soils, whose compositions have been determined, be grouped into two groups so that the members of one group will show a molecular ratio of silica to combined alumina and iron oxide less than 2 and the other more than 2, it is found that such a grouping is approximately identical with one made on the basis of friability and plasticity—the non-friable group has a ratio greater than 2, the friable group less than 2.

In using the ratio $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ for the whole soil it is admitted as an obvious fact that the relation of the physical properties of the soil and its composition may be of significance only for those classes which are high in clay and low in such discrete particles as quartz. The highly quartzose soils mostly belong in the very sandy group, which normally is characterized by high friability—unless it should be better in this instance to use the term "incoherency" or "looseness" as distinguished from friableness, in that the former term implies ready separation of the individual grains, whereas the latter term implies aggregation of the particles where the binding force is short of a state of marked hardness or consolidation. To what limit the content of intact mineral fragments large enough to exert a pronounced physical influence may extend without causing too great vitiation in the significance of the comparisons has not been determined, and need not be insofar as it vitally affects the meaning of indicated trends in soils of the kind found in many parts of Central America, since it is known that many of these are extremely low in gritty material, Most of the types under discussion contain no visible quartz or other hard grains. All but two of the samples of the friable soil group contain less than 7 per cent of sands, four have less than 1 per cent, and the average is 2.6 per cent, not including the two samples referred to, which contain approximately 23 per cent each (see table 4). Probably there is not much free primary quartz in the

finer constituents, since many of the soils come from basic igneous rocks, containing little or no quartz. Mineralogical analyses of the surface and sub-layers of the Arraiján clay (samples 30514 and 30515) have shown that the determinable minerals constitute only a trace of mica in the silt separate. Also only a trace of mica was found in the Columbiana clay, which is one of the most representative members of the group of friable soils.

Returning to the profile of the Aragon clay (see table 1) we find that the material of the entire section (samples 30567 to 30573 inclusive) above the zone of extremely low silica content is very friable and permeable. Below the zone of lowest silica, the material (sample 30575) shows what appears to be the effects of less intensive weathering, as measured by the silica : iron plus alumina ratio, that is 1.6 as against an average of .55 in the four horizons above. Farther down, the material of the "rotten rock" zone (sample 30576) indicates still greater diminution in the intensity of weathering, and according to the ratio employed above, belongs in the class of soil materials having properties opposite to those of the friable group, although this particular material is not very plastic and with removal of the discrete particles probably would fit into the friable group.

So deeply has weathering extended in the locality that the exact nature of the parent rock can not be readily determined in many places, although it probably belongs to the basic igneous group, along with some admixture of volcanic ash. In any case a study of the profile of the Aragon clay indicates that much silica has been lost in the weathering of the material lying above the zone containing an appreciable amount of incompletely decomposed parent rock particles, whereas the iron and alumina have shown a gain, both in proportion to the silica of this highly weathered material and to the amount of iron and alumina contained in the less modified zone beneath. Just why there is a decrease of silica downward is not understood. Accumulating colluvial material may have had something to do with this, or optimum conditions for removal of the silica and accumulation of iron and alumina may have existed in the lower layers. The Columbiana soil which is a good illustration of intense weathering, does not show a similar downward decrease of silica and an increase of iron and alumina (see table 1).

GROUP I: FRIABLE SOILS

Table 1 shows the chemical composition of 24 fine-textured soils (including substrata) from humid tropical Central America, grouped on the basis of a molecular ratio of $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ = less than 2. Compared with most of the upland clay soils of humid United States, all of these soils are distinctly more friable in all parts of their profiles, and they are much more permeable and resistant to erosion. Compared with one another, those that are highest in iron and alumina and lowest in silica are the more friable, permeable, and resistant to erosion. The material of the most friable or the most weathered layers shows no visible swelling or shrinking at the extremes of moisture content.

TABLE 5

Physical properties, parent material, and drainage of friable types

TYPE AND LOCALITY	SAMPLE NUMBER	POSITION	UNDERLYING MATERIAL	DEPTH	COLOR	CONSISTENCY	DRAINAGE
				inches			
Espiritu Santo clay. Top of Espiritu Santo Mts. 2 mi. N. Espiritu Santo, Honduras	28126	Nearly flat (About 4000 ft.)	Mica schist	24–36	Yellowish-brown	Moderately friable, brittle (moist)	Good
Arraiján clay. Arraiján, R. P.	30514	Gentle slope (480 ft.)	Igneous basic (dioritic)	0–3	Brownish	Slightly crumbled (dry)	Good
	30515		Igneous basic (dioritic)	3–30	Red	Slightly friable to moderately stiff, about like subsoil of Mecklenburg soils (moist)	Good
	30516		Igneous basic (dioritic)	30–40	Purplish, grayish and yellowish	Friable, contains some soft partly decayed rock (moist)	Good
	50317		Igneous basic (dioritic)	40–52	Purplish and grayish	Friable, considerable partly decayed rock (moist)	Good
Turrialba silty clay. Turrialba, C. R.	30557	Flat, lower slope	Slope-base material—probably volcanic ash and igneous	0–14	Brown	Friable (moist)	Good
	30558		Slope-base material—probably volcanic ash and igneous	14–32	Brown and rusty brown	Friable (moist)	Fairly good
	30559		Slope-base material—probably volcanic ash and igneous	32–60	Dark-brown	Friable (wet)	Imperfect

	30560		Slope-base material—probably volcanic ash and igneous	60–90	Black and rusty-brown and contains segregated iron	Friable (saturated)	Poor—near water-table
Aragon clay. 1 mi. West Turrialba, C. R.	30567	Gentle slope (2,100 ft.)	Probably feldspar porphyry and volcanic ash	0–11	Brown	Crumbled-fine fragments (dry)	Good
	30568		Probably feldspar porphyry and volcanic ash	11–20	Yellowish-brown	Friable (dry)	Good
	30569			20–40	Ocherous yellow	Very friable (slightly moist)	Good
	30570		Probably feldspar porphyry and volcanic ash	40–96	Ocherous yellow, some soft whitish particles	Very friable (moist)	Good
	30571		Probably feldspar porphyry and volcanic ash	96–132	Ocherous yellow, some soft whitish particles	Very friable (moist)	Good
	30572		Probably feldspar porphyry and volcanic ash	132–144	Buff-colored	Compact, friable (moist)	Good
	30573		Probably feldspar porphyry and volcanic ash	144–162	Reddish-yellow; some whitish and greenish soft decayed rock	Friable (moist)	Good
	30574		Probably feldspar porphyry and volcanic ash	162–202	Mainly greenish and whitish. Appearance of decayed rock, but decomposed and soft; same material to 35 ft.	Friable (moist)	Good

TABLE 5—*Continued*

TYPE AND LOCALITY	SAMPLE NUMBER	POSITION	UNDERLYING MATERIAL	DEPTH	COLOR	CONSISTENCY	DRAINAGE
				inches			
Aragon clay. 1 mi. West Turrialba, C. R.	30575		Probably feldspar porphyry and volcanic ash	At 35 ft.	Speckled olive and reddish brown. Soft, rotten rock of light weight	Brittle (moist)	Good
Columbiana clay. Columbiana, C. R.	30584	Nearly flat (about 500 ft.)	Outwash from volcanic and igneous basics	0–24	Chocolate-brown	Friable-crumbly (moist)	Good
	30585			24–65	Slightly reddish-brown	Friable-crumbly (moist)	Good
	30586		Outwash from volcanic and igneous basics	65–108	Rusty-brown and reddish, with grayish specks of soft rotten rock	Crushes easily	Good
Uruca loam, deep subsoil. Laguna, C. R.	30608	Moderately steep (5,800 ft.)	Mainly volcanic ash	92–102	Buff; some soft whitish particles	Compact in situ; crushes easily (moist)	Good
Cukra clay. Near S. end Pearl Lagoon, C. R.	30644	Flat (40 ft.)	Diorite	0–7	Reddish-brown	Friable (moist)	Good
	30645		Diorite	7–60	Reddish-brown	Friable (moist)	Good

This grouping seems to bring out a correlation between chemical composition and physical properties as carefully determined in the field (see table 5). There is a range from 5 to 41.87 per cent of silica and from 31.19 to 66.72 per cent of combined iron and alumina in the group of friable soils (see table 3), and the averages for these constituents are 29.3 and 49.19 per cent, respectively. The extremes of these ranges point to soil properties of opposite characteristics:

(*a*) To permeable, friable open soils, which show no perceptible volumetric changes with wetting and drying, in one direction—that of low silica and high iron and alumina, and (*b*) to non-friable, plastic or stiff soils, which shrink and crack on drying and swell to a corresponding degree with wetting, in the other direction—where the ratio of the constituents named are reversed.

Table 5 shows some of the most outstanding physical properties of this group.

GROUP II: PLASTIC SOILS

Using the molecular ratio $\frac{SiO_2}{Al_2O_3 + Fe_2O_3} = 2$ or more, as a dividing line, 24 other upland soils (including substrata) collected from the same humid-tropical region have been grouped into table 2 and designated as a group of non-friable or stiff soils. Most of these are clays, but they range to clay loam and in one case to loam (see table 4). The average content of material coarser than silt in 18 of the samples is 9.4 per cent and the average of the colloids is 72.7, with a maximum range to 90.4 per cent. In the group of more friable soils the average of colloids is 71.9, with a maximum range of 91 per cent.

In the main, these types are stiff and plastic, a few are brittle, and some are friable (see table 6). In some degree the friability of a few of the subsections is due to the presence of incompletely decayed rock particles, including some free quartz; but most of the stiff to plastic soils are as heavy textured as the most friable of the other group. Table 6 shows the most outstanding physical properties of this group.

Taking the subsoil of the San Pablo clay (sample 31356), as an example of extreme plasticity, we find in the field the material to be so extremely dense and impermeable that it retains its intimately associated water almost as tenaceously as if it were water of combination. Under this condition the interstitial space is so choked that there is extreme retardation in the circulation of both water and air. In the dry season a shallow surface layer of this type—that containing a fair supply of organic matter—cracks and recracks to form a loose or fine-fragmental soil, which becomes highly desiccated. Immediately beneath this parched layer the clay is moist and plastic throughout the dry season; yet deep-rooted crops such as orange trees, suffer severely or die on the type because they are unable to take sufficient moisture out of the putty-like clay. All crops wilt, parch, or die, showing unmistakably that the trouble is inadequacy of available moisture.

TABLE 6

Physical properties, parent material, and drainage of types largely non-friable

TYPE AND LOCALITY	SAMPLE NUMBER	POSITION	UNDERLYING MATERIAL	DEPTH	COLOR	CONSISTENCY	DRAINAGE
				inches			
Lancatillal clay loam. Near Lancatillal, near Guatemala-Honduras boundary	28109	Moderately steep, (about 1,500 ft.)	Hornblende-gabbro	0–8	Dark-brown	Moderately friable (moist)	Good
	28110		Hornblende-gabbro	8–18	Greenish-brown containing dark partly decomposed rock	Slightly plastic (moist)	Fair
La Francia clay. 3 mi. S. La Francia, Honduras	28111	Steep (about 2,500 ft.)	Limestone	0–2	Brownish-red	Friable (moist)	Good
	28112		Limestone	0–36	Red	Friable (moist)	Good
Talladega clay. Espiritu Santo, Honduras	28123	Steep (about 2,500 ft.)	Mica schist	0–3	Light-brown	Moderately friable, greasy feel (dry); plastic when moist	Good
	28124	Steep (about 2,500 ft.)	Mica schist	0–20	Red	Stiff and brittle; contains some quartz and schist particles (moist)	Good
Tosentales clay. 6 mi. N. Tosentales, Honduras	28148	Steep (about 3,500 ft.)	Grano-diorite	0–36	Red	Friable, contains some rock particles (moist)	Good
Chandler loam. 5. mi. N. Tosentales, Honduras	28154	Moderately steep	Mica schist	6–36	Yellow	Friable, contains some mica flakes (moist)	Good

Santa Rosa clay. 1 mi. E. Limon, R. P.	30522	Nearly flat (about 200 ft.)	Limestone	0–6	Brown	Slightly crumbly (moist)	Good
	30523		Limestone	6–22	Yellow	Very plastic and sticky (moist)	Imperfect
Uruca clay loam. 5 mi. N. San Jose, C. R.	30533	Gentle slope (about 4,000 ft.)	Volcanic ash	0–9	Dark-brown	Friable (dry); considerable grit	Good
	30534		Volcanic ash	9–13	Brown	Coarse-crumbly or small-cloddy (dry); slightly plastic when moist	Fair
	30535		Volcanic ash	13–40	Mottled yellowish-brown and buff	Cracks into clods on drying, plastic when moist	Fair
	30536		Volcanic ash	40–47	Brown	Friable (moist)	Good
Aragon clay. 1 mi. W. Turrialba, C. R.	30576	Gentle slope	Same as of 30567 (see table V)	At 37 ft.	Speckled bluish gray and ocherous yellow	Brittle (moist)	Good
Bluefields clay. Bluefields, Nicaragua	30653	Gentle slope (about 90 ft.)	Diorite and possibly some of the associated acidic cobbles	0–8	Light-brown	Plastic (moist)	Medium
	30654		Diorite and possibly some of the associated acidic cobbles	8–40	Mottled red and bluish-gray	Very plastic (moist)	Poor
	30655		Diorite and possibly some of the associated acidic cobbles	40–120	Mottled white and red	Plastic (moist)	Poor

TABLE 6—*Continued*

TYPE AND LOCALITY	SAMPLE NUMBER	POSITION	UNDERLYING MATERIAL	DEPTH	COLOR	CONSISTENCY	DRAINAGE
				inches			
Vinces clay. Vinces, Ecuador	31222	Flattish hillock (about 80 ft.)	Old alluvium	0–14	Brown	Cracked into hard clods (dry); plastic when moist	Fair
	31223		Old alluvium	14–42	Yellowish-brown some gray mottling	Plastic when moist	Fair
	31224		Old alluvium	42–120	Mottled bluish-gray and yellow	Plastic when moist	Poor
	31225		Old alluvium	120–160	Mottled yellowish-brown, yellow and bluish-gray, dark segregated iron	Compact	Poor
San Pablo clay. Summit, C. Z.	31355	Flat depression (about 225 ft.)	Probably limestone	0–7	Mottled brown and yellow	Cracks into small hard clods (dry); plastic when moist	
	31356		Probably limestone	7–48	Yellow	Very plastic, sticky and dense (moist)	

This soil is of limestone origin. It occupies a low position of poor drainage. In the wet season it is continuously water-logged and crops on it are seriously damaged by an excess of moisture. Weathering has been restricted to the surficial layer in this poorly aerated material.

The molecular ratio of silica to combined iron and alumina for this type is 4.6 in the soil and 2.8 in the subsoil.

In general this group of soils approximates the physical properties of the San Pablo clay. Outstanding exceptions, as previously noted, appear to be due largely to an excess of hard rock particles; but some of the soils, such as

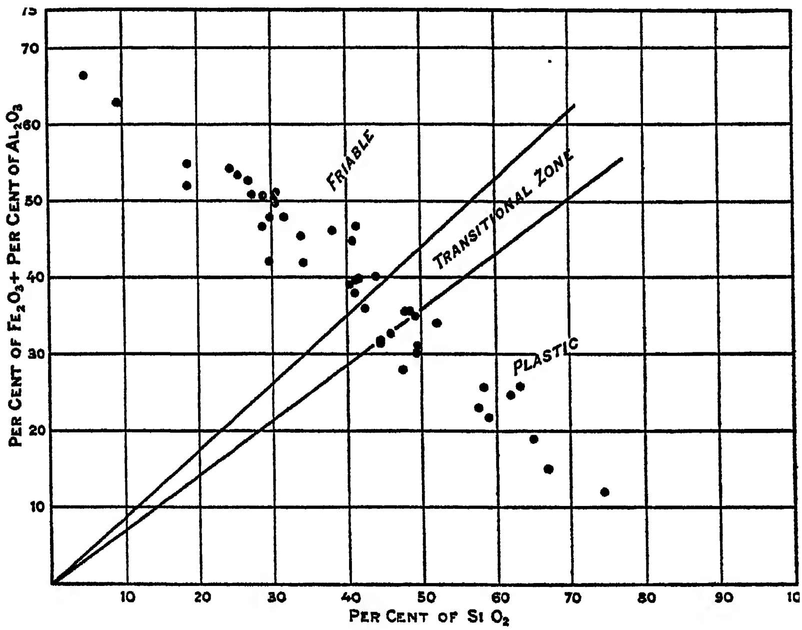


FIG. 1. PERCENTAGE RELATION OF SILICA TO IRON AND ALUMINA

samples 28111 and 28112, show a degree of friability that can not be accounted for solely by the presence of gritty material. If the basis of separating the soils had been on the amount and character of the contained colloids these friable types might have fallen into the opposite group.

Figure 1 graphically represents the relation of silica, by percentage, to iron and alumina, with a gradational zone rather arbitrarily drawn to separate roughly the areas of friable and non-friable soils.

RATIO OF IRON AND ALUMINA TO COMBINED WATER

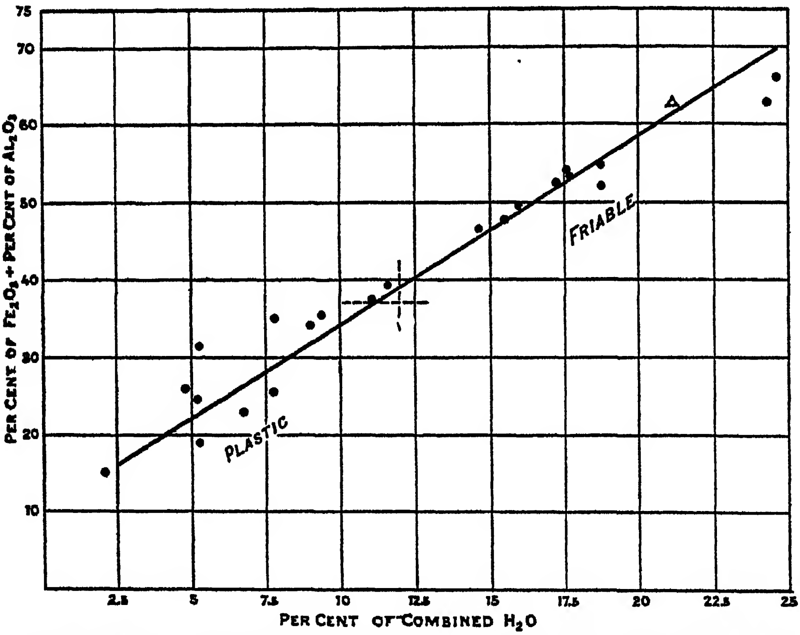
Figure 2, plotted from percentages,[3] shows the ratio of iron and alumina to combined water. On the basis of the samples for which the combined water

[3] Loss on ignition less CO_2 from carbonates, and less organic matter determined by weighing CO_2 evolved from combustion.

has been determined, the graph indicates that this form of water is proportional to the iron and alumina content. It thus appears that the iron and alumina in these types at least are neither more nor less hydrated in the one group than in the other. Somewhere along the line of ascending values there is a point beyond which the soils are markedly friable and below which they are stiff, but this point seemingly does not necessarily mark any sharp break in the ratio.

CONTENT OF BASES

If the soils of the humic tropics have been severely leached in those types where weathering has been most intense, it would seem the content of lime,



Δ Represents sample of extremely lateritic soil from Northern Guam—a red soil with less then 1% silica.

FIG. 2. PERCENTAGE RELATION OF IRON AND ALUMINA TO COMBINED WATER

magnesia, soda, and potash should be relatively low. The average percentage of these four bases found in the friable group is 1.32 and the range is from 0.13 to 6.55 against an average of 4.50 and a range of 0.85 to 17.17 in the group of stiff soils. The maximum range of bases in the former group goes up to 1.95 per cent, with the exception of 3 samples. Figure 3, shows something of the general tendency in the percentage relation of iron and alumina to that of the combined mono- and divalent bases.

It has been shown that the physical properties of colloids vary somewhat with the character and amount of absorbed bases. In arid regions it may be possible that soils with a high content of sodium salts, for example, will show

more deflocculation, plasticity, and imperviousness than the silica : iron plus alumina would indicate.

RELATED NORTH AMERICAN SOILS

Table 7 shows chemical analyses of a number of humid North American red to deep-red upland clay soils derived from rocks of the types corresponding to the parent rocks of many of the tropical soils discussed, such as basic igneous rocks, limestone, and granite. The friability of none of these is developed to the degree encountered in the tropical soils of low $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ ratios de-

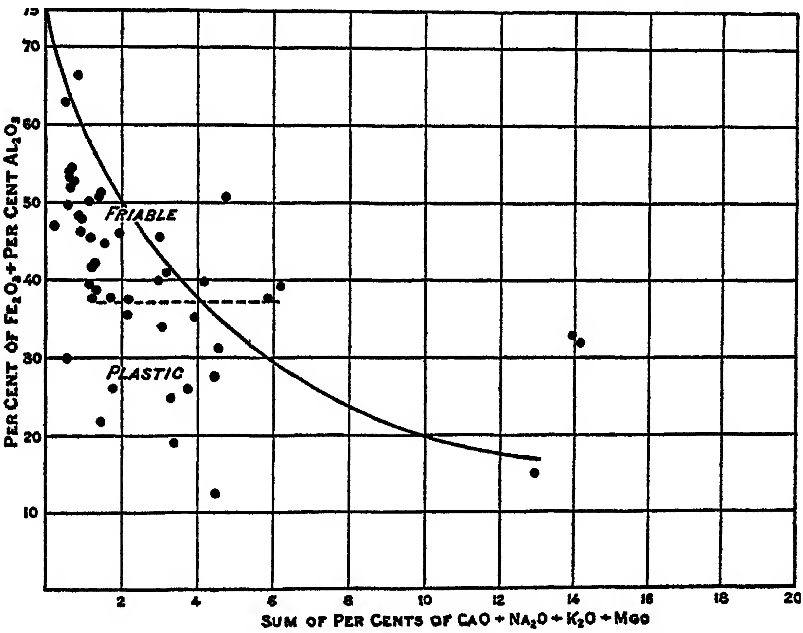


FIG. 3. PERCENTAGE RELATION OF IRON AND ALUMINA TO BASES

scribed above; but the properties of the one having a molecular ratio $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ equals less than 2, that is the Davidson clay loam, resemble very closely those of the highly friable class of tropical soils. The Davidson clay loam is locally known as "push land" because the crumbly material does not scour well over the moldboard of plows. Exactly the same property is exhibited by the well-defined friable Columbiana clay of eastern Costa Rica. Both types in the moist condition adhere to the plow share apparently more from force of impact than from mere stickiness, since neither soil is especially sticky (the Columbiana clay shows almost no stickiness). The Davidson clay loam is so crumbly that the plow simply pushes it aside instead of turning a more or less firm furrow-slice. The same thing is true of the Columbiana clay.

TABLE 7

Chemical analyses of granite, limestone and basic igneous soils from humid Southeastern United States

Type, location and parent rock	Sample number	Depth	SiO_2	TiO_2	Fe_2O_3	Al_2O_3	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	N	CO_2 from carbonates	Ignition loss	Organic matter	Mols $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
		inches	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	
Mecklenburg clay loam, Mecklenburg County, North Carolina, diorite	24004	0–4	46.41	3.68	17.14	21.85	0.46	1.44	0.93	0.48	1.20	0.24	0.11	0	.....	0.53	3.3
	24005	4–24	43.30	2.03	15.29	25.02	0.21	1.48	1.76	0.41	0.89	0.25	0.10	0	.....	0.41	2.1
	24006	24–36	46.70	2.03	12.87	25.21	0.16	3.09	2.04	0.27	2.04	0.23	0.06	0	.....	0.33	2.4
Davidson (stony) clay loam, Talbot County, Georgia	A	0–8	38.53	1.71	22.91	24.14	0.09	0.18	0.18	0.11	0.03	0.21	.....	.....	.....	.....	1.7
Diabase parent rock, unweathered	B	....	51.76	1.43	14.16	14.34	0.19	10.66	5.69	0.32	2.09	0.16	.....	.....	.....	.....	.....
Cecil clay loam, Talbot County Georgia	D	0–6	52.81	0.96	8.73	26.65	0.01	0.20	0.35	1.23	0.08	0.13	.....	.....	.....	.....	2.7
Gneiss, parent rock unweathered	E	....	73.63	0.46	2.53	13.55	0.02	1.32	0.64	5.30	2.12	0.15	.....	.....	.....	.....	.....
Cecil clay, Mecklenburg County, North Carolina, granite	15*	0–6	66.49	1.02	7.43	17.11	0.51	0.36	0.31	0.62	0.16	0.17	.....	0	8.06	2.47	5.1
	16*	6–36	44.15	1.14	16.23	27.58	0.03	0.44	0.09	0.61	0.15	0.15	.....	0	11.83	2.90	2.0
Cecil clay loam, Wilkes County, Georgia, schist and gneiss	4†	0–9	83.81	0.80	2.97	7.70	0.20	0.28	0.15	0.79	0.43	0.06	0.03	0	2.89	0.56	14.8
	5†	9–18	75.68	0.87	4.21	12.95	0.16	0.43	0.14	0.73	0.24	0.05	0.04	0	5.50	1.08	8.2
Decatur clay loam, Jackson County, Alabama, limestone	3*	0–4	79.35	1.15	4.44	8.89	0.07	0.63	0.39	0.67	0.24	0.18	.....	0	4.80	1.96	11.5
	4*	4–15	74.81	1.28	5.28	12.80	0.05	0.40	0.33	0.75	0.16	0.15	.....	0	4.63	0.93	7.8

* U. S. Dept. Agr. Bul. 122.

† U. S. Dept. Agr. Bul. 1311.

It will be noticed that some of the Cecil types approach the less-than 2 silica:iron plus alumina ratio. One of the properties of the Cecil is that it swells but little on wetting and shrinks but slightly on drying, cracks of considerable size rarely being seen, even in highly desiccated sectional exposures. This, as pointed out, is also one of the properties of the highly friable tropical soils. The red limestone clayey soils (Decatur) of eastern Tennessee and northern Alabama are related in their properties to the friable soils of the Tropics, as are also the red "iron-ore lands" of northeast Texas.

Most of the soils of table 7 are much more friable than most of those of the tropical types of high molecular silica:iron plus alumina ratio, not because they contain more gritty material, but for some other reason, which may be due to the effect of more intense weathering. It would be interesting in this connection to compare the very plastic Iredell clay of the Piedmont region of southeastern United States, a basic igneous rock soil, with the similar highly plastic subsoil of the San Pablo clay; but complete chemical analyses are not available for the former type.

This point will not be discussed further than to observe that it indicates that similar processes of weathering are going on in the tropics and in parts of southeastern United States—that the principal difference seems to be not so much in the kind of weathering as in the degree of weathering, that of the humid tropics being much more intense in many instances.

In this connection it may be added, by way of illustration, that the shallow mica-schist soils of Northern Honduras essentially are duplicates, both physically and chemically, of the mica-schist soils (Talledega) of the southern extension of the Blue Ridge Mountains of the United States, and that the highly quartzose soils of the northeastern Nicaraguan "sandy savanas" include soils which are typical of the Florida Flatwoods, such as the St. Johns, Plummer, and Norfolk sands.

GENERAL CONCLUSIONS

It is believed that investigations in this field of soil study hold out promising results, not only from the standpoint of scientific interest, but possibly also from the practical standpoint. Enough has been pointed out to show that all soils of extremely fine texture do not behave physically in the same way. One type of clay shrinks little or none with wetting and drying, and another swells and shrinks greatly. The latter type is of the plastic group of soils which are so impervious in the extreme cases as to have very poor drainage and aeration. It is the clay of this last group that may be expected to give most trouble as subgrade material in building highways, and it is soil of this kind that is most difficult to cultivate. If some ready means could be devised for distinguishing between these types of clay by those not generally familiar with methods of identifying soil types, here might be something of value to the highway engineer in determining the quality of a doubtful clay soil for a road subgrade.

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PLOWING THE COLUMBIANA CLAY IN EASTERN COSTA RICA

The picture was taken about 9 a.m. It had been raining all the morning and every day for a week or more previously, yet this extremely fine-grained soil was turning up into an excellent crumbly tilth and showed almost no stickiness.

INFLUENCE OF FORM, SOIL-ZONE, AND FINENESS OF LIME AND MAGNESIA INCORPORATIONS UPON OUTGO OF CALCIUM AND MAGNESIUM[1]

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The immediate and continued effects of economic additions of lime are influenced by several factors. Biological activation may deplete the additions through the formation of the more readily leached neutral salts. The speed and nature of the absorption reactions determine the persistence of carbonates and the formation of non-carbonate residues, the nature of which influences the future availability of the unleached fractions. Recently it has been pointed out (4) that the non-carbonate residues apparently become progressively more tenaciously fixed in the soil through the process of aging. These factors are themselves affected by the relative fineness and solubility of the additions and the method of their incorporation, and by the amount and periodicity of rainfall.

This article deals with the leachings of calcium and magnesium from a fallow brown loam during a 4-year period. Chemically equivalent additions of $Ca(OH)_2$, four separates, and a composite of both high-calcic limestone and dolomite were made in a 34-tank installation. Influence of *zone of incorporation* is also included as a major consideration.

EXPERIMENTAL

The results given were obtained by analyses of leachings, collection of which was determined by the distribution of annual rainfall. All additions were made at the constant equivalence of 2,000 pounds of CaO, or 3,570 pounds of $CaCO_3$, per 2,000,000 pounds of soil, moisture-free basis. In one series the additions were made only to the upper half, or zone, of surface soil, whereas in a second series the additions were incorporated only with the lower half, or zone. Details as to soil, chemical and mechanical analyses of additions, and illustrations of the lysimeter installations are given in a previous

[1] The results were obtained by the use of equipment donated by the American Limestone Company of Knoxville and through a fellowship endowment maintained by the National Lime Association.

[2] The analyses for the first two years were made by Mr. Hanvey Stanford, while those the third and fourth years were made respectively by Mr. T. D. Harden and Dr. R. M. Barnette, all formerly fellowship assistants at this Station.

TABLE 1

Total calcium leached during 4 years from surface-zone additions of 2000 pounds of CaO and equivalent limestone and dolomite separates

$CaCO_3$-equivalent per 2,000,000 pounds of moisture-free loam soil

TREATMENT	FIRST ANNUAL PERIOD					SECOND ANNUAL PERIOD				THIRD ANNUAL PERIOD				FOURTH ANNUAL PERIOD			TOTAL FOR 4-YEAR PERIOD	4-YEAR INCREASE IN OUTGO OVER CONTROLS	
	May to September	September to January	January to March	March to May	Total	May to December	December to February	February to May	Total	May to September	September to February	February to May	Total	May to December	December to May	Total		Actual	On basis of additions
	lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*per cent*
Controls	128	136	53	40	357	108	43	37	188	69	81	27	177	126	50	176	898	...	....
$Ca(OH)_2$	240	201	55	47	543	138	43	39	220	79	82	27	188	149	41	190	1141	243	6.8
L. S. 10–20	133	127	49	38	347	116	40	35	191	79	107	30	216	169	59	228	982	84	2.4
L. S. 20–40	123	149	53	32	357	134	47	40	221	96	112	33	241	184	51	235	1054	156	4.5
L. S. 40–80	140	178	53	47	418	152	45	38	235	115	107	27	249	155	41	196	1098	200	5.8 *
L. S. 80–200	149	184	56	38	427	155	43	40	238	109	98	27	234	154	44	198	1097	199	5.8
L. S. Comp.	131	180	52	42	405	85	39	33	157	82	96	27	205	147	45	192	959	61	1.8
Dol. 10–20	119	136	46	35	336	78	42	34	154	65	100	27	192	204	55	259	941	43	2.2
Dol. 20–40	137	144	51	44	376	81	46	37	164	92	99	27	218	178	49	227	985	87	4.5
Dol. 40–80	129	167	51	39	386	116	42	37	195	95	109	31	235	162	49	211	1027	129	6.6 †
Dol. 80–200	140	177	47	35	399	128	44	34	206	111	94	30	235	160	49	209	1049	151	7.8
Dol. Comp.	128	150	52	37	367	116	48	43	207	95	102	28	225	152	48	200	999	101	5.2

* On basis of $CaCO_3$ = content of limestone separates.

† On basis of $CaCO_3$ = content of dolomite separates.

TABLE 2

Total calcium leached during 4 years from subsurface-zone additions of 2,000 pounds of CaO and equivalent dolomite separates

$CaCO_3$-equivalent per 2,000,000 pounds of moisture-free loam soil

TREATMENT	FIRST ANNUAL PERIOD					SECOND ANNUAL PERIOD				THIRD ANNUAL PERIOD				FOURTH ANNUAL PERIOD			TOTAL FOR 4-YEAR PERIOD	4-YEAR INCREASE IN OUTGO OVER CONTROLS	
	May to September	September to January	January to March	March to May	Total	May to December	December to February	February to May	Total	May to September	September to February	February to May	Total	May to December	December to May	Total		Actual	On basis of additions
	lbs.	*lbs.*	*lbs.*	*lbs*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*per cent*
Control	128	136	53	40	357	108	43	37	188	69	81	27	177	126	50	176	898	...	....
$Ca(OH)_2$	412	315	135	202	1064	210	113	115	438	133	121	60	314	188	77	265	2081	1183	59.2
L. S.‡ 10–20	124	140	63	76	403	148	98	100	346	137	124	59	320	222	88	310	1379	481	14.0*
L. S. 20–40	157	212	87	52	508	236	123	122	481	158	162	69	389	216	99	315	1693	795	23.1*
L. S. 40–80	216	276	127	167	786	258	131	129	518	170	147	79	396	198	90	288	1988	1090	31.7*
L. S. 80–200	281	299	131	186	897	242	128	127	497	157	135	67	359	196	85	281	2034	1136	33.0*
L. S. Comp.	199	244	95	144	682	214	121	116	451	159	132	64	355	200	90	290	1778	880	25.6*
Dol.§ 10–20	127	126	49	41	343	115	36	41	192	84	81	30	195	119	48	167	897	—1	...†
Dol. 20–40	105	143	49	58	355	127	62	63	252	85	103	43	231	140	61	201	1039	141	7.2†
Dol. 40–80	139	153	55	72	419	128	81	76	285	108	102	65	275	141	71	212	1191	293	15.1†
Dol. 80–200	157	175	88	88	479	161	89	87	337	131	113	45	289	132	63	195	1300	402	20.7†
Dol. Comp.	145	153	54	80	432	139	72	69	280	101	100	44	245	138	59	197	1154	256	13.2†

* On basis of $CaCO_3 \Leftrightarrow$ content of limestone separates.

† On basis of $CaCO_3 \Leftrightarrow$ content of dolomite separates.

‡ L. S. = Limestone.

§ Dol. = Dolomite.

TABLE 3

Total magnesium leached during 4-years from surface-zone additions of 2,000 pounds of CaO and equivalent limestone and dolomite separates

$CaCO_3$-equivalent per 2,000,000 pounds of moisture-free loam soil

TREATMENT	FIRST ANNUAL PERIOD					SECOND ANNUAL PERIOD				THIRD ANNUAL PERIOD				FOURTH ANNUAL PERIOD			TOTAL FOR 4-YEAR PERIOD	4-YEAR INCREASE IN OUTGO OVER CONTROLS	
	May to September	September to January	January to March	March to May	Total	May to December	December to February	February to May	Total	May to September	September to February	February to May	Total	May to December	December to May	Total		Actual	On basis of additions
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	per cent
Controls	34	39	18	20	111	34	20	20	74	31	32	14	77	43	31	74	336	...	...
$Ca(OH)_2$	59	52	19	22	152	38	21	21	80	24	26	15	65	43	24	67	364	28	...
L. S. 10–20	31	33	17	19	100	41	19	21	81	29	27	20	76	47	26	73	330	−6	...
L. S. 20–40	33	40	15	27	115	39	22	19	80	31	33	17	81	52	22	74	350	14	5.4
L. S. 40–80	39	46	16	16	117	46	20	17	83	36	31	15	82	46	19	65	347	11	4.2 *
L. S. 80–200	43	48	18	14	123	53	20	19	92	33	34	15	82	43	23	66	363	27	10.4
L. S. Comp.	34	46	17	19	116	30	19	19	68	26	28	18	72	45	25	70	326	−10	...
Dol. 10–20	31	36	17	14	98	30	20	23	73	23	37	15	75	59	26	85	331	−5	...
Dol. 20–40	35	35	16	16	102	39	21	19	79	28	38	16	82	58	33	91	354	18	1.0
Dol. 40–80	37	43	17	15	112	40	20	19	79	24	34	19	77	61	30	91	359	23	1.3 †
Dol. 80–200	36	47	17	14	114	44	20	18	82	36	36	19	91	69	36	105	392	56	3.2
Dol. Comp.	34	43	17	14	108	39	21	21	81	34	29	18	81	54	26	80	350	14	0.8

* On basis of MgO content, terms of $CaCO_3 \Leftrightarrow$, of limestone separates.

† On basis of MgO content, terms of $CaCO_3 \Leftrightarrow$, of dolomite separates.

TABLE 4

Total magnesium leached during 4 years from subsurface-zone additions of 2,000 pounds of CaO and equivalent limestone and dolomite separates

$CaCO_3$-equivalent per 2,000,000 pounds of moisture-free loam soil

TREATMENT	FIRST ANNUAL PERIOD					SECOND ANNUAL PERIOD				THIRD ANNUAL PERIOD				FOURTH ANNUAL PERIOD			TOTAL FOR 4-YEAR PERIOD	4-YEAR INCREASE IN OUTGO OVER CONTROLS	
	May to September	September to January	January to March	March to May	Total	May to December	December to February	February to May	Total	May to September	September to February	February to May	Total	May to December	December to May	Total		Actual	On basis of additions
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	per cent
Controls	34	39	18	20	111	34	20	20	74	31	32	14	77	43	31	74	336	...	...
$Ca(OH)_2$	37	25	14	20	96	36	21	21	78	18	23	17	58	33	36	69	301	−35	...
L. S. 10–20	36	33	19	25	113	38	25	25	88	25	27	19	71	63	26	89	361	25	9.7*
L. S. 20–40	42	41	20	18	121	43	25	26	94	26	28	16	70	42	31	73	358	22	8.5*
L. S. 40–80	44	42	20	27	133	37	31	22	90	22	25	20	67	32	22	54	344	8	3.1*
L. S. 80–200	47	39	18	26	130	40	24	21	85	23	24	18	65	32	21	53	333	−3	...
L. S. Comp.	44	43	19	32	138	37	30	23	90	21	23	16	60	42	26	68	356	20	7.7*
Dol. 10–20	39	42	20	19	120	57	28	28	113	53	53	27	133	82	42	124	490	154	8.7†
Dol. 20–40	32	62	26	35	155	87	48	49	184	58	81	40	179	102	61	163	681	345	19.4†
Dol. 40–80	47	89	40	50	226	95	65	60	220	77	79	56	212	128	62	190	848	512	28.8†
Dol. 80–200	77	114	47	64	302	116	73	72	261	90	89	39	218	106	60	166	947	611	34.4†
Dol. Comp.	54	85	36	52	227	97	56	55	208	62	77	40	179	100	55	155	769	433	24.4†

* On basis MgO content, terms of $CaCO_3$ ≎, of limestone separates.

† On basis MgO content, terms of $CaCO_3$ ≎, of dolomite separates.

TABLE 5

Total calcium-magnesium leached during 4 years from surface-zone additions of 2,000 pounds and equivalent limestone and dolomite separates

$CaCO_3$-equivalent per 2,000,000 pounds of moisture-free loam soil

TREATMENT	FIRST ANNUAL PERIOD					SECOND ANNUAL PERIOD				THIRD ANNUAL PERIOD				FOURTH ANNUAL PERIOD			TOTAL FOR 4-YEAR PERIOD	4-YEAR INCREASE IN OUTGO OVER CONTROLS	
	May to September	September to January	January to March	March to May	Total	May to December	December to February	February to May	Total	May to September	September to February	February to May	Total	May to December	December to May	Total		Actual	On basis of additions
	lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*per cent*
Controls	162	175	71	60	468	142	63	57	262	100	113	41	254	169	81	250	1234	...	...
$Ca(OH)_2$	299	253	74	69	695	176	64	60	300	103	108	42	253	192	65	257	1505	271	7.6
L. S. 10–20	164	160	66	57	447	157	59	56	272	108	134	50	292	216	85	301	1312	78	2.2
L. S. 20–40	156	189	68	59	472	173	69	59	301	127	145	50	322	236	73	309	1404	170	4.8
L. S. 40–80	179	224	69	63	535	198	65	55	318	151	138	42	331	201	60	261	1445	211	5.9
L. S. 80–200	192	232	74	52	550	208	63	59	330	142	132	42	316	197	67	264	1460	226	6.3
L. S. Comp.	165	226	69	61	521	115	58	52	225	108	124	45	277	192	70	262	1285	51	1.4
Dol. 10–20	150	172	63	49	434	108	62	57	227	88	137	42	267	263	81	344	1272	38	1.1
Dol. 20–40	172	179	67	60	478	120	67	56	243	120	137	43	300	236	82	318	1339	105	2.9
Dol. 40–80	166	210	68	54	498	156	62	56	274	119	143	50	312	223	79	302	1386	152	4.3
Dol. 80–200	176	224	64	49	513	172	64	52	288	147	130	49	326	229	85	314	1441	207	5.8
Dol. Comp.	162	193	69	51	475	155	69	64	288	129	131	46	306	206	74	280	1349	115	3.2

TABLE 6

Total calcium-magnesium leached during 4 years from subsurface-zone additions of 2,000 pounds of CaO and equivalent limestone and dolomite separates

$CaCO_3$-equivalent per 2,000,000 pounds moisture-free loam soil

TREATMENT	FIRST ANNUAL PERIOD					SECOND ANNUAL PERIOD				THIRD ANNUAL PERIOD				FOURTH ANNUAL PERIOD			TOTAL FOR 4-YEAR PERIOD	4-YEAR INCREASE IN OUTGO OVER CONTROLS	
	May to September	September to January	January to March	March to May	Total	May to December	December to February	February to May	Total	May to September	September to February	February to May	Total	May to December	December to May	Total		Actual	On basis of additions
	lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*per cent*
Controls	162	175	71	60	468	142	63	57	262	100	113	41	254	169	81	250	1234	....	....
$Ca(OH)_2$	449	340	149	222	1160	246	134	136	516	151	144	77	372	221	113	334	2382	1148	32.2
L. S. 10–20	160	173	82	101	516	186	123	125	434	162	151	78	391	285	114	399	1740	506	14.2
L. S. 20–40	199	253	107	70	629	279	148	148	575	184	190	85	459	258	130	388	2051	817	22.9
L. S. 40–80	260	318	147	194	919	295	162	151	608	192	172	99	463	230	112	342	2332	1098	30.8
L. S. 80–200	328	338	149	212	1027	282	152	148	582	180	159	85	424	228	106	334	2367	1133	31.7
L. S. Comp.	243	287	114	176	820	251	151	139	541	180	155	80	415	242	116	358	2134	900	25.2
Dol. 10–20	166	168	69	60	463	172	64	69	305	137	134	57	328	201	90	291	1387	153	4.3
Dol. 20–40	137	205	75	93	510	214	110	112	436	143	184	83	410	242	122	364	1720	486	13.6
Dol. 40–80	186	242	95	122	645	223	146	136	505	185	181	121	487	269	133	402	2039	805	22.6
Dol. 80–200	234	289	135	152	781	277	162	159	598	221	202	84	507	238	123	361	2247	1013	28.4
Dol. Comp.	199	238	90	132	659	236	128	124	488	163	177	84	424	238	114	352	1923	689	19.3

contribution (5). The calcium and magnesium contents of the rainfall have been determined over a period of years (2); but these are considered as being included in the outgo from the two controls, the results from which are averaged.

DISCUSSION

The findings are given in tables 1 to 6, in terms of $CaCO_3$-equivalence per 2,000,000 pounds of moisture-free soil for each collection during each annual period and for the 4-year period. The averaged amount of calcium lost from the controls for the 4-year period was deducted from the outgo from each treated tank to give the increase attributable to the addition. Each amount so found is expressed both as pounds and as percentage of calcium content of the addition. The magnesium results are expressed in the same manner. The hydrated lime was so pure that its meagre content of magnesium could be disregarded. The precipitations for the four years, 1921–1925, were 52.52, 52.03, 46.99, and 39.25 inches, respectively.

Calcium outgo

Surface-zone additions.—The untreated soil was acid and devoid of carbonates, so that the total calcium outgo from the controls is considered as having been derived from the hydrolysis of the native calcium silicates and by the neutralization of biological end-products (table 1). Such neutralization might be effected either by bicarbonates evolved through hydrolysis, or by direct action of the biologically-induced acids upon the silicate complexes. The total $CaCO_3$-equivalent outgo of 898 pounds from the controls for the 4-year period represents 10 per cent of the 0.4495 per cent $CaCO_3$-equivalent of the total non-carbonate CaO content. From previous studies upon the same soil (1) it may be stated that the full increase in outgo from the $Ca(OH)_2$ addition was derived from the hydrolysis of absorption complexes formed within a period of 10 days. Those absorption compounds were derived in part from the direct combination of acid-reacting materials and $Ca(OH)_2$ and in part from their subsequent reaction with the $CaCO_3$ derived from that part of the hydrate addition which was not directly absorbed. A similar speedy fixation may be attributed to the finer limestone separates; but a previous contribution (5) has shown that considerable carbonate residues from the coarser separates were still present after 4 years. The increases in outgo in those instances are therefore considered as having been derived jointly from hydrolysis of absorption compounds and from solution of carbonate residuals.

The extent of disintegration of the limestone additions in the surface zone should be gauged by the previously reported carbonate study (5), rather than by the increased calcium content of the leachings. These are subject to the absorptive action of the unsaturated subsurface zone which tends to cause a uniform calcium outgo; therefore, in 11 of the 12 comparisons between

the first annual losses from the controls and those from $Ca(OH)_2$ and limestone and dolomite groups the differences due to additions are all less than 55 pounds. The one exception is that of the hydrated lime treatment, which gave for the first year an increase of 186 pounds, or 76 per cent of the 243-pound total for the 4-year period.

The limestone and dolomite group average for the second year was 191 pounds less than that for the first year, and also less than the group averages of the third and fourth years. The total calcium losses from both controls and treatments for the initial year were about twice as large as those for either of the succeeding annual periods. Enhanced biological activities, as a result of the aeration incident to screening and mixing before placement, are thus reflected, irrespective of additions. This phase of the subject will be considered in a subsequent contribution.

But in spite of the equalizing action of the untreated subsurface zone the the effects of form and fineness are registered in all of the 4-year totals and in many of the losses for the annual periods. The greatest increase in outgo through the full soil depth for the 4-year period was obtained from the hydrated lime, yet this increase of 243 pounds is only 6.8 per cent of the addition. For the limestone group the maximum increase in outgo was 200 pounds, or 5.8 per cent of the addition. This increase was obtained from both of the two finer separates, 40–80-mesh and 80–200-mesh. The actual outgo of calcium in each of the 4 dolomite separates was less than that from its corresponding limestone separate, but the results are magnified when expressed in percentage on the basis of the lesser occurrence of $CaCO_3$ in the dolomite.

Subsurface-zone additions.—The annual calcium outgo from each of the several subsurface-zone additions was greatest during the first year and, with the exception of that from the 10–20-mesh dolomite separate, every annual outgo gave a progressive decrease thereafter (table 2). In the absence of opportunity for absorption after movement of the free-soil water from the zone of treatment, direct determinations of the differences caused by variation in form and fineness of materials are recorded. All treatments show consistent increases in calcium outgo for annual and total periods, although the effect of the greater solubility of the hydrated lime and the influence of fineness upon solution and disintegration of both limestone and dolomite separates are more definitely shown. The greater availability of the hydrated lime, or its greater yield of total calcium salts, is especially marked during the first year. The increased outgo of 707 pounds during that year was equivalent to nearly 60 per cent of the outgo during the full 4-year period. Although the hydrate addition gave the maximum outgo for the first year, the 80–200-mesh limestone separate gave a greater outgo during each of the succeeding 3 years, so that the increases from hydrated lime and 80–200-mesh additions for the 4-year period were practically identical, namely, 33 per cent. To only a slightly less extent was the same true also for the increase

of 31.7 per cent from the 40–80-mesh limestone. The order of increase over the control-outgo was in accord with the increase in fineness of separates.

The calcium losses from the low-calcium dolomite group were uniformly less than those from the limestone group, but the influence of fineness upon

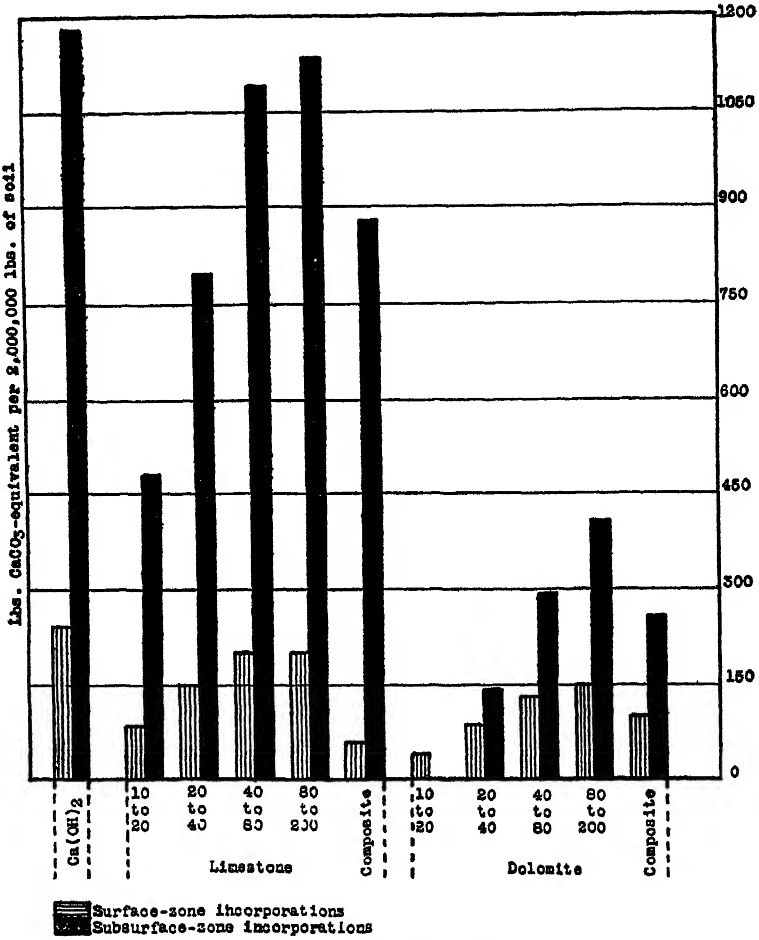

FIG. 1. TOTAL CALCIUM OUTGO IN EXCESS OF THAT FROM LOAM CONTROLS DURING 4 YEARS AS A RESULT OF 2000-POUND CaO-EQUIVALENT ADDITIONS OF $Ca(OH)_2$ AND LIMESTONE AND DOLOMITE SEPARATES OF 10–20-, 20–40-, 40–80- AND 80–200-MESH FINENESS—SURFACE-ZONE AND SUBSURFACE-ZONE INCORPORATIONS

Terms of $CaCO_3$-equivalence per 2,000,000 pounds of soil, moisture-free basis

outgo is especially marked. The annual recoveries from the 10–20-mesh separate were slightly less than those from the control for 2 years and slightly more for the other two annual periods, with a 4-year difference of only 1 pound. Though inactive for the first annual period, the 20–40-mesh separate

gave increases for the succeeding 3 years. The differences between the losses from the controls and those from the two finer separates were quite appreciable for each of the 4 annual periods. It will be remembered that the calcium losses from the dolomite series, with a maximum increase of 20.7 per cent for the finest subdivision, are calculated on the basis of the $CaCO_3$ content of the dolomite.

In comparing the increased losses from the subsurface-zone additions with corresponding losses from the surface-zone additions, it is evident that the

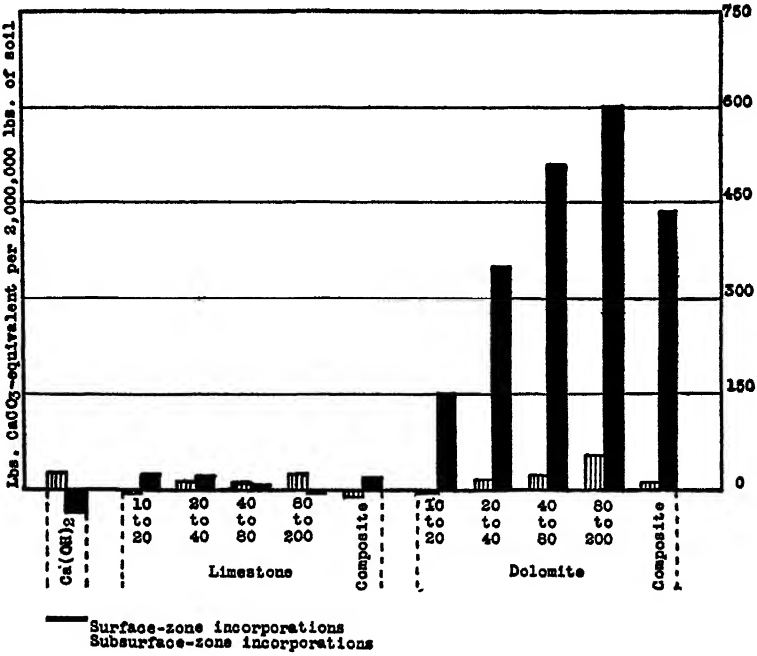

FIG. 2. TOTAL MAGNESIUM OUTGO IN VARIANCE FROM THAT OF LOAM CONTROLS DURING 4 YEARS AS A RESULT OF 2000-POUND CaO-EQUIVALENT ADDITIONS OF $Ca(OH)_2$ AND LIMESTONE AND DOLOMITE SEPARATES OF 10–20-, 20–40-, 40–80- AND 80–200-MESH FINENESS—SURFACE-ZONE AND SUBSURFACE-ZONE INCORPORATIONS

Terms of $CaCO_3$-equivalence per 2,000,000 pounds of soil, moisture-free basis

deeper incorporations yielded a higher calcium content to the leachings in every case. These differences were greatest, 26.3 per cent and 27.2 per cent, respectively, for the hydrated lime and for the 80–200-mesh limestone. Partial absorption from the calcium-impregnated leachings during their movement through the layer of untreated soil is one factor responsible for these consistent differences; but, in addition, previously reported results (5) upon carbonate residuals demonstrated that the disintegration of carbonate additions was more rapid and extensive in the lower zone. In the case of the

coarsest separate, the lower-zone incorporation gave a disintegration 8 times as great as that brought about by the same incorporation in the upper zone (5).

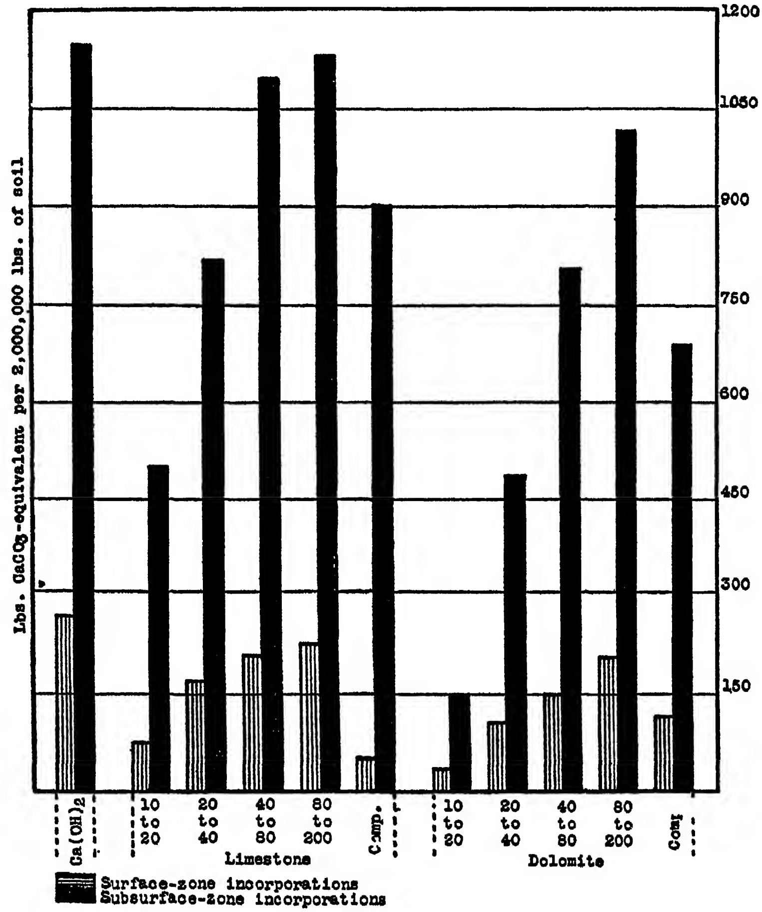

FIG. 3. TOTAL CALCIUM-MAGNESIUM OUTGO IN EXCESS OF THAT FROM LOAM CONTROLS DURING 4 YEARS AS A RESULT OF 2000-POUND CaO-EQUIVALENT ADDITIONS OF $Ca(OH)_2$ AND LIMESTONE AND DOLOMITE SEPARATES OF 10–20-, 20–40, 40–80- AND 80–200-MESH FINENESS—SURFACE-ZONE AND SUBSURFACE-ZONE INCORPORATIONS

Terms of $CaCO_3$-equivalence per 2,000,000 pounds of soil, moisture-free basis

Magnesium outgo

Surface-zone additions.—The 4-year magnesium outgo from the untreated carbonate-free acid control was equivalent to only 336 pounds of $CaCO_3$, as compared with a 898-pound $CaCO_3$-equivalence of calcium (table 3). Ultimate analyses of the soil used showed that the total CaO content of 0.2517 per cent was equivalent to 8990 pounds of $CaCO_3$, whereas the MgO con-

tent of 0.4116 per cent was equivalent to 20,440 pounds of $CaCO_3$. From this it is seen that the native magnesium was very much more firmly fixed.

With the exception of the outgo from the hydrated lime treatment during the first year, there was no appreciable increase in magnesium outgo. Previously reported findings (4) from full-depth lime additions to the same soil showed a repression of magnesium outgo and the same finding appears for the subsurface-zone incorporations of table 4. It would seem, therefore, that the increased magnesium content from the hydrated lime during the initial year may be attributed to interchange exerted by surface-zone-derived neutral calcic salts during their passage through the untreated subsurface zone. The differences in magnesium outgo from the limestone series are small, varying from plus to minus, with only 3 small plus gains for 4-year totals, the maximum being only 10 per cent of the magnesium carbonate impurity of the limestone.

The annual and 4-year magnesium totals from the dolomite series are small, and the 4 plus totals represent but small fractions—a maximum of 3.2 per cent—of the magnesium content of the dolomite additions. The part of the added magnesium carbonate which was disintegrated was either held in the upper zone of treatment, or passing to the lower zone, it was there absorbed.

Subsurface-zone additions.—During 3 of the 4 years the hydrated lime caused a repression of magnesium outgo from the zone where calcium was in excess (table 4). This is in accord with our previous findings (4).

In the limestone group there were small increases in outgo for the 5 treatments during the first 2 years; but the reverse was true with one exception during the second 2 years. The four totals which gave plus quantities are all small and since they represent mere fractions of the magnesium carbonate content of the added limestone, which had fully disintegrated in two cases, it is evident that none of the native magnesium was forced into the leachings by interchange.

The annual amounts of magnesium coming from the slowly disintegrating 10–20-mesh dolomite separate were, in order, only 9, 39, 56, and 50 pounds. The other separates yielded larger quantities for annuals and totals in general accord with the order of fineness.

In comparing the magnesium increases derived from surface and subsurface additions, every annual and each total period shows a greater outgo from the subsurface-zone additions. The maximum difference of 31 2 per cent of the added $MgCO_3$ was obtained from the 80–200-mesh dolomite separate.

Total calcium-magnesium

Surface-zone additions.—The difference in zone of incorporation involves either the factor of basic interchange, or the reverse factor of "reciprocal repression" (3, 4). It is therefore necessary to consider the total calcium-magnesium outgo. This is done in tables 5 and 6 for the surface-zone and subsurface-zone incorporations, respectively. In these tables the full value of

3,570 pounds $CaCO_3$-equivalence (2,000 pounds of CaO) of additions is used as the basis of calculation for both high-calcic and dolomitic materials.

The calcium-magnesium losses from controls and those from hydrated lime are practically identical for the third and fourth years; but the larger increase from the hydrated lime during the first year and the smaller for the second give an aggregate equivalent to 7.6 per cent of the addition.

In 10 of the high-calcic limestone additions to the tanks the magnesium impurity represents an appreciable aggregate, whereas in the 10 dolomite additions the calcium and magnesium carbonates are in near-equivalence. Neither annual nor total calcium-magnesium losses from the coarser high-calcic limestone differ greatly from those yielded by the controls; but, with increasing fineness, there is a definite increase in outgo. The orders of fineness and of increased outgo are parallel, but, as a result of the absorptive action of the untreated subsurface zone the maximum loss, that from the 80–200-mesh separate, is only 6.3 per cent of the addition. In slightly less degree, the same may be said of the corresponding dolomite separates.

Subsurface-zone additions.—The hydrated lime gave the greatest calcium-magnesium outgo of 1148 pounds, or 32.2 per cent of the addition (table 6). As a result of the minus quantity of magnesium, due to the repression of magnesium solubility and an outgo less than that from the controls, the total calcium-magnesium loss is less than the total outgo of calcium.

With the exception of the 10–20-mesh dolomite separate for the first year, all additions registered an appreciable increased annual outgo. The maximum calcium-magnesium outgo from the $Ca(OH)_2$ addition was closely followed in order by limestone of 80–200-mesh and of 40–80-mesh and by dolomite of 80–200-mesh fineness with 1133 pounds, 1098 pounds, and 1013 pounds, respectively, or 31.7 per cent, 30.8 per cent, and 28.4 per cent. When thus incorporated, it would appear that, for the 4-year period, the hydrated lime, two finer limestone separates, and the finest dolomite separates may be considered of about equivalent values. As the two limestone separates increase in size, the disintegration, or greater solubility, of the high-calcic limestone is more pronouncedly shown.

In each of 54 of the 55 annual and total comparisons between increases from surface-zone and subsurface-zone incorporations, the latter shows the greater outgo.

Taken as a whole, under all conditions, the results from the composites may be said to conform most closely to the responses from the 20–40-mesh separates.

SUMMARY

Results are given from a 4-year study with a 34-unit lysimeter installation to determine the influence of form, soil-zone and fineness of lime and magnesia incorporations upon the outgo of calcium and magnesium from a constant equivalent of 2,000 pounds of CaO.

The maximum increase in calcium outgo from surface-zone incorporations

during 4 years was only 6.8 per cent of the addition and although some influence of form and fineness was recorded, the untreated subsurface zone tended to produce a uniform outgo.

In the absence of the retardative effect of a layer of untreated soil, the lower zone incorporations gave a maximum increased outgo of 33 per cent of the addition. Although the hydrated lime gave the greatest outgo during the first year—about 60 per cent of its total—its final increase was almost identical with the increases from the two finer limestone separates.

The losses from the high-calcic additions during the first year were uniformly maximum with decided decreases for the next three years for both zones. The differences due to fineness, zone, and time were not so great for the dolomite additions, but they showed positive effects from the imposed conditions.

There was a very little difference between the magnesia outgo from the controls and the losses from either limestone or dolomite additions to the surface zone The losses from the subsurface-zone incorporations were consistently greater than those from the surface zone incorporations. Both zones generally gave the maximum annual outgo during the first year. The influence of fineness of dolomite separates was especially marked in the subsurface outgo for both annual and 4-year periods.

In the case of the completely disintegrated finer limestone separates in the subsurface zone, there was no increased magnesium outgo from the decomposition of the magnesium content of the limestone.

Repressed magnesia solubility was indicated by the high-calcic additions to the lower zone.

The total calcium-magnesium leachings from the surface-zone incorporations were small, comparable for limestone and dolomite, and related to the degree of fineness.

The total calcium-magnesia leachings from the subsurface-zone incorporations were uniformly greater than those from the surface-zone incorporations. Limestone separates gave totals uniformly higher than those from the corresponding dolomite separates, the disparity decreasing with increasing fineness. The total outgo from $Ca(OH)_2$ and that from 100-mesh limestone and dolomite were almost identical.

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THE USE OF OAT STRAW IN A SYSTEM OF SOIL FERTILITY

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The results of many experiments (1, 2, 5, 10, 13, 14, 15, 17, 18, and 19) indicate that the addition of straw to a soil will decrease the growth and yield of the succeeding crop. There are, however, a few instances (3, 4, 5, and 12) where investigators have found that straw added to the soil has not caused a decrease in crop growth and that in some cases beneficial effects have been secured.

Sufficient evidence has been produced to prove that the detrimental effect of straw generally evidenced on the growth of the succeeding crop is due to a decrease in available nitrogen, which is utilized by the organisms involved in the decomposition of the straw, and, if nitrogen is the limiting factor in crop production, a decrease in growth results.

Several methods of overcoming this difficulty have been suggested, such as plowing the straw under in the early fall so that some decomposition will occur before the crop is planted the following season; adding sodium nitrate or ammonium sulfate in amounts large enough to furnish available nitrogen for the organisms which decompose the cellulose and carbohydrate material in the straw; or applying the straw to a legume crop before the latter is plowed under. The latter practice has been followed in the management of the crop residue plots at this station for several years.

EXPERIMENTAL

Since so much data have been published on the harmful effects of various kinds of straw, it seemed advisable to study the problem further and to determine under what conditions oat straw can be returned to the soil without interfering with the growth and yield of succeeding crops. The chief criticism of many of the experiments which have been conducted, is that the rates of application of the straw were much heavier than the amount of straw produced by an acre of grain. Considerable variation in yield of straw is secured on different soils and also from different kinds and varieties of grain grown on the same soil, consequently it is very difficult to select any definite amount of straw as representative of all conditions. The variation in yield of oat straw at this station is from ½ to 1 ton per acre. Communications from several of the

[1] The authors wish to thank Dr. P. E. Brown for helpful suggestions received in connection with this study.

agricultural experiment stations in the corn belt give the following yields of straw from small grain; Indiana—oats $\frac{1}{2}$ to 1 ton, wheat and rye about $1\frac{1}{2}$ tons; Illinois—oats $\frac{1}{3}$ to $1\frac{1}{6}$ tons, wheat $2\frac{1}{3}$ tons; and Missouri—oats $2\frac{1}{4}$ tons, wheat $1\frac{3}{4}$ tons.

Since under most conditions some straw is utilized in farmyard manure, the rate of application of straw if it were returned to the soil on which it was grown, except under a strictly grain system of farming, would be less than the yield of straw per acre. In this experiment applications of oat straw at rates of $\frac{1}{2}$ and 1 ton per acre were used because these amounts, according to the data obtained, are not far from the average yield in this state and in adjoining states except Missouri.

Three different soil types were used in the investigation. All of these soils are of glacial origin, and the type name, reaction, total nitrogen, and organic carbon content of each soil are given in table 1.

TABLE 1

Total nitrogen and organic carbon content and the reaction of the soils used

SOIL TYPE	TOTAL N PER 2,000,000 POUNDS OF SOIL	TOTAL ORGANIC CARBON PER 2,000,000 POUNDS OF SOIL	REACTION
	pounds	*pounds*	
Webster silt loam	6,600	67,200	Basic
Clarion loam	2,800	......	Neutral
Carrington loam	2,000	43,000	Medium acid

TABLE 2

Total nitrogen and carbon content of the oat straw, red clover, and Hubam clover used

MATERIAL	TOTAL NITROGEN	TOTAL CARBON
	per cent	*per cent*
Oat straw	0.7	40.0
Red clover	1.7	41.0
Hubam clover	2.1	40.5

GREENHOUSE STUDY

Four-gallon pots were filled with the Webster silt loam and Carrington loam and treated with oat straw cut into 1 inch lengths at the rates of $\frac{1}{2}$ and 1 ton per acre. Red clover, Hubam clover (annual white sweet clover), sodium nitrate, and ammonium sulfate were added to various pots in combination with the straw. The red clover and Hubam clover were applied at the rates of $\frac{1}{2}$ and 1 ton per acre with the straw and were mixed thoroughly with the soil. The sodium nitrate and ammonium sulfate were added to the dry straw before it was mixed with the soil so that these salts would be in immediate contact with the straw and would aid in its decomposition by furnishing available nitrogen for the microorganisms. The analyses of the organic materials added are given in table 2.

TABLE

Effect of the addition of oat straw, alone and in combination with red clover, Hubam clover, sodium nitrate, and ammonium sulfate, on the accumulation of nitrate in Carrington loam and in Webster silt loam

SOIL TYPE	TREATMENT	RATE PER ACRE					NITRATE CONTENT OF SOIL			
		Straw	Red clover	Hubam clover	$NaNO_3$	$(NH_4)_2SO_4$	January 9	February 28	April 3	May 12
		tons	*tons*	*tons*	*pounds*	*pounds*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Carrington loam	None						38	60	40	86
	Straw	½					36	65	38	70
	Straw	1					33	63	38	76
	Straw, red clover	½	½				31	62	34	76
	Straw, red clover	1	½				29	62	33	86
	Straw, $NaNO_3$	½			30.5		44	68	41	88
	Straw, $NaNO_3$	1			61.0		42	77	41	80
	Straw, $(NH_4)_2SO_4$	½				23.6	42	59	37	82
	Straw, $(NH_4)_2SO_4$	1				46 2	40	65	36	80
	Red clover		½				35	58	30	78
Webster silt loam	None						47	68	40	126
	Straw	½					40	66	40	102
	Straw	1					36	64	48	122
	Straw, red clover	½	½				36	63	40	110
	Straw, red clover	1	½				42	66	47	122
	Straw, Hubam clover	½		1			52	76	44	117
	Straw, Hubam clover	1		1			47	74	46	135
	Straw, $NaNO_3$	½			30.5		57	56	44	132
	Straw, $NaNO_3$	1			61.0		52	66	58	140
	Straw, $(NH_4)_2SO_4$	½				23.6	33	58	42	134
	Straw, $(NH_4)_2SO_4$	1				46.2	36	66	43	146
	Red clover		1				56	62	54	118
	Hubam clover			1			61	85	78	155

The first series of greenhouse pots were kept fallow and the nitrate content of the soils receiving the various treatments was determined about every six weeks after the experiment was started. The results of these analyses are given in table 3. It is evident from these data that the accumulation of nitrate has not been retarded to any great extent by the addition of straw to these soils.

In another experiment in which the straw was ground very fine, added to the Carrington loam, and incubated at 27°C. for different lengths of time, a considerable effect on the nitrate accumulation in the soil was produced. These data are given in table 4.

TABLE 4

Effect of finely ground oat straw applied at different rates, and incubated for different lengths of time on the accumulation of nitrate in Carrington loam

TREATMENT	RATE PER ACRE	TIME OF INCUBATION AT 27°C.			
		2 weeks N as NO_3	4 weeks N as NO_3	6 weeks N as NO_3	8 weeks N as NO_3
	tons	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
None		14	26	40	50
Straw	½	8	18	44	50
Straw	1½	3	13	28	40
Straw	5	0	2	7	20

TABLE 5

Effect of oat straw on the growth of wheat when applied to Webster silt loam, alone and in combination with red and Hubam clover

TREATMENT	RATE PER ACRE			TOTAL YIELD	
	Straw	Red clover	Hubam clover	Green weight	Dry weight
	tons	*tons*	*tons*	*gm.*	*gm.*
None				174	74
Straw	1			153	63
Straw and red clover	1	½		174	77
Straw and Hubam clover	1		1	192	81
Red clover		½		168	72
Hubam clover			1	162	68

The data given in table 4 agree with those of many other investigators. Since straw is not finely ground or chopped up into short lengths when applied in the field, however, such data are of little value except to indicate what takes place in the soil in immediate contact with the straw.

Another series of pots filled with Webster silt loam was treated at the same time as the series that was fallowed and planted to spring wheat. Throughout the growing period very little difference could be noticed among the various treatments. When the crop was harvested, it was evident that the straw alone had depressed the growth of the crop slightly. The results of this experiment are given in table 5.

FIELD STUDIES

Field investigations were conducted in connection with the greenhouse studies in the same soil types as are given in table 1. The effect of the addition

TABLE 6

Effect of the addition of straw to field plots, alone and in combination with alfalfa and Hubam clover

TREATMENT	SOIL TYPE	NITROGEN AS NITRATE		
		Nov. 12, 1924	April 10, 1925	May 4, 1925
		p.p.m.	*p.p.m.*	*p.p.m.*
Alfalfa	Carrington loam	8	16	62
Alfalfa, straw	Carrington loam	9	13	59
Hubam clover	Webster silt loam	7	21	58
Hubam clover, straw	Webster silt loam	3	21	45

TABLE 7

Effect of straw and straw mixed with Hubam clover on the accumulation of nitrate in soil in contact with the residue as compared with soil not in contact with the residue

SOURCE OF SOIL	N AS NO_3	
	Webster silt loam	Clarion loam
	p.p.m.	*p.p.m.*
Free from straw	99	12.7
Contact with straw	53	8.7
Contact with straw mixed with Hubam clover	113	19.4

TABLE 8

Effect of straw on the yield of corn when applied alone and in combination with red and Hubam clover

Rate of applications given in tons per acre

TREATMENT	MATERIALS APPLIED			YIELD OF CORN PER ACRE
	Straw	Red clover	Hubam clover	
				bushels
None				69.7
Red clover		$\frac{3}{4}$		76.1
Hubam clover			$1\frac{1}{5}$	81.0
Oat straw	$\frac{3}{4}$			79.3
Red clover and oat straw	$\frac{3}{4}$	$\frac{3}{4}$		76.1
Hubam clover and oat straw	$\frac{3}{4}$		$1\frac{1}{5}$	78.9
None				75.0

of straw in the fall, with and without legumes was studied in the first experiment. The results are given in table 6.

These soils were plowed in October. The alfalfa that was turned under

was the growth made after the third cutting, and was estimated at one-half ton per acre. The Hubam clover was the growth that occurred following winter wheat and was estimated at one and one-fourth tons per acre. Straw was applied at the rate of 1 ton per acre. The analyses were made on composite samples, each of which was composed of 10 samples taken from different portions of each plot. These samples represented the surface 6 inches of soil and since only a portion was in contact with the layer of straw between the furrows, this soil did not represent the effect of the straw on the soil immediately in contact with it. Consequently on May 21, 1925 another group of samples was taken from the plots which had grown wheat and Hubam clover in 1924, and had received an application of straw, which was plowed under in October. In many places it was possible to secure straw from the layer which was turned under and which was not mixed with Hubam clover. Other bunches of straw contained a large amount of Hubam clover. In every place where a sample was taken from the soil in contact with the residues another sample was taken from the same furrow at a distance of about two to three inches from the residues which were plowed under. The results of these analyses were averaged and are given in table 7.

The season was very dry and warm through April and May and much larger amounts of nitrate accumulated in field soils than is usually the case. There is no doubt, however, that the straw caused some reduction in nitrates in the soil that was in contact with it, but when Hubam clover was present, there was an increase in nitrates over the amount present in the soil that was not in contact with any residue.

In order to determine more accurately what effect the straw has on the growth of crops, 7 field plots located on Carrington loam at the Agronomy Farm were treated with straw, red clover, and Hubam clover, alone and in combination, and were planted to corn. The results of the first year are given in table 8.

The differences in the yield of corn in this experiment do not indicate that oat straw has caused any decrease in the yield. The results of the yields secured from other plots to which straw is applied with the second crop of red clover and plowed under in the fall also, do not show any harmful effects due to the treatment. These results, however, do not apply to soils which have a low content of available nitrogen; before any final statement can be made, therefore, further investigation is necessary on the effect on such soils of the plowing under of straw with the second crop of red clover.

SUMMARY

The effect of applications of oat straw on the accumulation of nitrate in soils when applied alone and in combination with red clover, Hubam clover, sodium nitrate, and ammonium sulfate was studied under greenhouse conditions. The addition of oat straw to a Webster silt loam and to a Carrington loam did not appreciably affect the accumulation of nitrates in these soils.

Wheat was also grown on one series of pots filled with Webster silt loam. Although no effect of the various treatments was noticeable in the development of the plants, the soil treated with oat straw alone yielded less than untreated soil.

A study of the nitrate accumulation in field soils to which oat straw had been applied and turned under with the second growth of red clover, Hubam clover, and alfalfa indicated that no retardation occurred except in that portion of the soil immediately in contact with straw which was not mixed with the legume.

The effect of additions of oat straw alone and in combination with red clover and Hubam clover to a Carrington loam had no retarding effect on the growth and yield of corn.

CONCLUSIONS

Without causing any injury to crop growth and yield, straw can be returned to many corn belt soils by spreading it on the second growth of red clover, on Hubam clover (annual white sweet clover), or on biennial sweet clover and by plowing in the fall wherever possible. The rate of application should not exceed one to one and one-half tons per acre.

The effect of large applications of straw on the growth of crops may be physical rather than biochemical since the straw reduces the nitrate content of only the soil in immediate contact with it.

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THE LOSS OF SOLUBLE SALTS IN RUNOFF WATER[1]

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Many determinations of the salt content of streams and underground waters have been made, but little attempt has been made to determine the loss of various plant nutrient elements due to surface runoff. Some work concerning this matter has been done at the Missouri Experiment Station in connection with the soil erosion studies which have been in progress for the past eight years. A few determinations of the loss of nitrogen in the runoff water were given in an earlier report (2). This paper covers determinations made on the runoff water from the erosion plots having different cultural and crop treatments during the year May 1, 1924 to April 30, 1925. This must be considered as a progress report, since the samples are still being collected and further determinations will be made in the future. The year under consideration, however, is complete within itself. The rainfall during this time was somewhat above normal, being 45.2 inches whereas the average during the past eight years has been only 36.3 inches and that at Columbia during the past thirty-four years has been 37.6 inches.

Most of the attention in this work has been given to the loss of those elements which are considered of greatest importance from the standpoint of soil fertility.

PLAN OF THE WORK

Immediately after each rain, samples of the runoff water were drawn from each tank with a sampling tube, brought to the laboratory, and filtered through clay filters. Aliquots were taken and the samples stored for analysis. All the samples obtained during a 3-month period were composited in order to reduce the number of chemical determinations. For the most part the standard methods of water analysis as published by the American Public Health Association (1) were followed in this work. Other colorimetric methods were substituted for phosphorus.

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The treatments of the various plots in this experiment were as follows:

Soil erosion experiments. Plan of treatments

PLOT	CROP	SOIL TREATMENT
1	Soybeans since 1923	Spaded 8 inches deep in spring and cultivated
	Rye as winter cover crop	Hoed in fall before seeding rye
2	No crop	Spaded 4 inches deep in spring and fallowed during season
3	No crop	Spaded 8 inches deep in spring and fallowed during season
4	Sod continually	Grass clipped and removed when necessary
5	Wheat annually	Spaded 8 inches deep in July and fallowed until October
6	Rotation—corn, wheat, clover*	Spaded 8 inches deep before corn, and hoed before wheat
7	Corn annually	Spaded 8 inches deep in spring. Corn cultivated

* During the year in which the results in this paper are reported this plot was in wheat followed by clover.

RESULTS

The analysis of the runoff from the various plots shows that the loss of soluble salts is a quantity worthy of consideration. The loss of plant-food materials is so large that it must be considered as one of the important means by which soils are depleted in certain of these elements. Table 1 shows that although the concentration is relatively low, the loss of mineral elements may make up a considerable proportion of the salt content found in our rivers. This fact becomes even more significant when we take into consideration the evaporation from stream water on its way to the sea.

The determinations made by McHargue and Peter (4) on water samples taken near the mouth of the Mississippi River show a decidedly greater concentration of calcium and magnesium than was present in the runoff from these plots, but the results with sulfur and potassium are not so widely different. The concentration of phosphorus is considerably higher in these samples than was reported by McHargue and Peter.

The results with calcium and sulfur on the sample from plot 4, May 1 to June 23, 1924 seemed too high, but because the amount of sample was limited, these determinations could not be repeated. The results of these two determinations, therefore, have not been included in table 2.

When the results are calculated to pounds per acre, the significance of the losses from a practical standpoint becomes more apparent. Table 2 shows the loss of the mineral elements as well as of the four forms of nitrogen. The loss of nitrogen by this means seems to be very slight. Some change in or even loss of nitrogen from these samples might be due to their long period of storage. However, tests made on fresh samples showed only traces of soluble nitrogen.

Most of the dissolved nitrogen was in organic form and the amount of nitrate nitrogen was surprisingly small. Of the mineral elements calcium and sulfur alone are lost in sufficient quantities to be of much practical importance, as may be seen from table 3. Attention might be called to the fact that the loss of calcium from wheat land has been 18.618 pounds per acre, an amount approximately three times that removed by the grain and straw of a 25-bushel wheat crop. The loss of calcium and sulfur from the uncropped fallow plots 2 and 3 is noticeably higher than from the other plots. The loss of potassium was highest from plot 4, whereas plot 1 showed the greatest loss of phosphorus. The loss of potassium in the runoff water from plots 2, 3, and 4 was greater than the amount ordinarily supplied by average applications of commercial fertilizer.

A comparison of tables 3 and 4 shows that the plant-food material lost in the form of soluble salts was small as compared with that lost in the solid material eroded from the plots that were cultivated a good portion of the year. On the other hand, the loss of plant-food material from sod land has been considerably greater in the form of soluble salts than in the eroded material.

Although tables 3 and 4 do not cover the same years, it is believed that the losses reported in table 4 are reasonably representative of the average for the duration of the experiment.

TOTAL SOLIDS

The total amount of soluble salts lost in the runoff water from these plots has been remarkably high for certain plots. Table 5 shows the loss of soluble salts per acre in comparison with the solid material eroded from the plots during the same period of time. It will be seen that in all the cultivated plots the solid material eroded is much the greater source of total material loss, but in the case of the plot in bluegrass, the weight of salts lost is 59.76 per cent of the weight of solid particles removed. From plot 6, which was in wheat followed by clover, the total loss of soluble salts was 6.96 per cent of the weight of sedimentary material removed. When the ignited salts are considered, approximately the same relation holds for the various plots. The relatively high loss of salts from plots 4 and 6 may be partly explained on the basis of results shown by LeClerc and Breazeale (3) who found that there may be a large amount of salts exuded from the surface of plant leaves and that these salts are washed off by rains. Plots 4 and 6 were covered with vegetation during the entire year whereas the mature crops of soybeans, of wheat, and of corn were removed from plots 1, 5, and 7 respectively. Plots 1 and 5 were then seeded to fall grains but the loss of salts from young plants is probably small as compared with olders ones. The grass on plot 4 is usually cut with a lawn mower and allowed to fall back on the plot. There is doubtless a large loss of salts from this material.

The percentage of the weight of soluble salts lost on ignition is greater in the case of plots 1, 4, 5, and 6 which are kept in crops most of the time. The

TABLE 1

Concentration of the various elements in the runoff water from different plots

PLOT	TREATMENT	DATES OF SAMPLING	RUN-OFF	N as NH_3	N AS ORGANIC	N AS NO_2	N AS NO_3	Ca	Mg	K	Na	S	P	TOTAL SOLIDS 103°C.	TOTAL SOLIDS IGNITED
			cu. ft.	*p.p.m.*	*p.p.m*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
1	Soybeans	May 1 to June 23, 1924	161.28	0.083	0.833	N.S.*	N.S.	5.60	0.29	0.45	0.51	2.82	0.12	92.0	28.0
		June 24 to July 31, 1924	116.38	0.042	0.500	Absent	Trace	3.81	0.13	0.45	0.79	3.53	0.25	50.0	23.5
		August 1 to October 31, February 1 to April 30, 1925	330.05	0.042	1.083	Absent	0.08	5.00	0.09	0.61	0.94	4.00	1.50	85.0	37.0
		November 1, 1924 to January 31, 1925	19.86	0.125	0.750	0.001	Trace	3.94	0.42	6.76	0.38	5.54	0.63	67.5	46.0
2	Spaded 4 inches	May 1 to June 23, 1924	167.85	Absent	0.833	N.S.	N.S.	6.51	0.32	1.74	1.15	8.63	0.50	142.5	65.5
		June 24 to July 31, 1924	128.39	Absent	0.667	Absent	0.08	4.75	0.35	4.15	0.77	4.51	0.30	70.0	38.0
		August 1 to October 31, February 1 to April 30, 1925	425.30	Absent	0.413	0.004	0.08	8.20	1.00	1.66	1.99	7.58	0.25	100.0	64.0
		November 1, 1924, to January 31, 1925	11.29	N.S.	N.S.	Absent	N.S.	3.81	0.20	1.83	1.95	5.03	0.25	61.0	42.5
3	Spaded 8 inches	May 1 to June 23, 1924	157.70	0.125	0.500	N.S.	N.S.	6.30	Trace	0.61	0.25	4.09	0.38	136.0	56.0
		June 24 to July 31, 1924	124.42	Absent	0.413	Absent	0.08	4.20	0.02	1.55	1.71	4.52	0.38	56.5	33.5
		August 1 to October 31, 1924	170.64	0.83	0.750	0.001	Trace	6.09	0.20	3.62	1.05	6.58	0.25	65.5	42.5
		November 1, 1924, to January 31, 1925	11.56	N.S.	N.S.	Absent	N.S.	5.33	0.35	0.35	0.40	6.17	5.00	115.0	87.0
		February 1 to April 30, 1924	268.04	Absent	0.583	Absent	N.S.	7.56	0.76	0.72	1.19	7.73	0.50	78.0	47.5

4	Sod	May 1 to June 23, 1924	81.94	Absent	0.833	N.S.	N.S.	33.57	Trace	4.44	2.38	30.07	0.30	143.5	52.0
		June 24 to July 31, 1924	64.69	Absent	0.083	N.S.	N.S.	4.93	Trace	1.37	2.35	2.34	0.30	66.0	34.0
		August 1 to October 31, 1924	110.23	N.S.	N.S.	Absent	N.S.	3.14	0.24	6.89	1.42	3.94	0.45	83.5	50.5
		November 1, 1924, to April 30, 1925	249.54	N.S.	N.S.	N.S.	N.S.	6.55	0.07	2.43	1.04	5.33	0.30	85.0	43.0
5	Wheat	May 1 to June 23, 1924	150.42	0.042	0.750	N.S.	N.S.	5.94	0.09	1.12	0.59	3.64	0.50	114.0	39.5
		June 24 to July 31, 1924	119.18	Absent	0.083	Absent	0.06	4.02	Trace	0.18	0.12	3.82	0.25	53.0	29.0
		August 1 to October 31, 1924	140.86	N.S.	N.S.	Absent	0.08	3.77	0.04	0.82	1.61	3.71	0.45	61.0	31.5
		November 1, 1924, to April 30, 1925	260.36	0.025	0.583	0.007	0.16	7.01	1.55	Trace	0.19	6.57	0.30	90.0	49.0
6	Wheat and clover	May 1 to June 23, 1924	89.54	0.025	0.250	N.S.	N.S.	4.88	Trace	0.70	0.26	3.34	0.45	136.5	64.0
		June 24 to July 31, 1924	93.78	Absent	0.083	N.S.	N.S.	3.06	0.07	1.08	0.75	2.13	0.12	40.5	22.0
		August 1, 1924, to April 30, 1925	211.18	0.500	0.583	Absent	0.14	12.03	0.23	0.41	0.13	6.82	0.12	82.32	41.47
7	Corn	May 1 to June 23, 1924	151.29	Absent	0.750	N.S.	N.S.	6.91	0.31	0.74	0.54	4.07	0.30	109.0	45.5
		June 24 to July 31, 1924	111.59	Absent	0.413	Absent	0.14	3.52	0.28	0.21	0.27	3.19	0.25	47.5	29.0
		August 1 to October 31, 1924	177.06	N.S.	N.S.	0.10	0.14	2.13	1.81	0.89	1.19	7.62	0.12	53 08	39.23
		November 1, 1924, to April 30, 1925	243.75	Absent	0.413	0.025	0.10	7.23	0.02	0.13	Trace	3.38	0.12	90.0	49.0

* N.S. = no sample.

TABLE 2

Chemical analysis of runoff water—erosion experiment—May 1, 1924, to April 30, 1925

Pounds of elements lost per acre

PLOT	DATE OF SAMPLING	N AS NH_3	N AS ORGANIC	N AS NO_2	N AS NO_3	Ca	Mg	K	Na	S	P	TOTAL SOLIDS (DRY)	TOTAL SOLIDS IGNITED
1	May 1 to June 23, 1924	0.067	0.671	N.S.*	N.S.	4.510	0.234	0.362	0.411	2.271	0.097	74.094	22.550
	June 24, to July 31, 1924	0.024	0.291	Absent	Trace	2.214	0.076	0.262	0.459	2.052	0.145	29.058	13.657
	February 1, to April 30, 1925	0.069	1.785	Absent	0.132	8.241	0.148	1.005	1.549	6.593	2.472	140.092	60.981
	August 1 to October 31, 1924												
	November 1, 1924, to January 31, 1925	0.012	0.074	0.0001	Trace	0.391	0.042	0.670	0.038	0.549	0.062	6.694	4.562
	Total	0.172	2.821	0.0001	0.132	15.356	0.500	2.299	2.457	11.465	2.766	249.938	101.750
2	May 1 to June 23, 1924	Absent	0.698	N.S.	N.S.	5.457	0.268	1.458	0.964	7.233	0.419	119.440	54.901
	June 24 to July 31, 1924	Absent	0.428	Absent	0.051	3.045	0.224	2.661	0.494	2.891	0.192	44.879	24.363
	August 1, to October 31, 1924	Absent	0.877	0.008	0.170	17.415	2.123	3.525	4.226	16.098	0.531	212.378	135.922
	February 1 to April 30, 1925												
	November 1, 1924, to January 31, 1925	N.S.	N.S.	Absent	N.S.	0.215	0.011	0.103	0.110	0.284	0.014	3.439	2.396
	Total		2.003	0.008	0.221	26.132	2.626	7.747	5.794	26.506	1.156	380.136	217.582
3	May 1 to June 23, 1924	0.097	0.394	N.S.	N.S.	4.961	Trace	0.480	0.197	3.221	0.299	107.099	44.099
	June 24 to July 31, 1924	Absent	0.257	Absent	0.050	2.609	0.012	0.963	1.062	2.808	0.236	35.104	20.814
	August 1 to October 31, 1924	0.071	0.639	0.001	Trace	5.189	0.170	3.085	0.895	5.607	0.213	55.813	36.215
	November 1, 1924, to January 31, 1925	N.S.	N.S.	Absent	N.S.	0.308	0.020	0.020	0.023	0.356	0.029	6.638	5.022
	February 1 to April 30, 1925	Absent	0.780	Absent	N.S.	10.119	1.017	0.964	1.593	10.346	0.670	104.402	63.578
	Total	0.168	2.070	0.001	0.050	23.186	1.219	5.512	3.770	22.338	1.447	309.056	169.728

4	May 1 to June 23, 1924	Absent	0.341	N.S.	N.S.	N.S.	Trace	1.817	0.974	N.S.	0.123	58.717	21.277
	June 24 to July 31, 1924	Absent	0.027	N.S.	N.S.	1.593	Trace	0.443	0.759	0.756	0 097	21.320	10.983
	August 1 to October 31, 1924	N.S.	N.S.	Absent	N.S.	1.728	0.132	3.793	0.782	2.169	0.248	45.962	27.797
	November 1, 1924, to January 31, 1925	N.S.	N.S.	N.S.	N.S.	8.162	0.087	3.028	1.296	6.642	0.374	105.919	53.582
	Total		0.368			11.483	0.219	9.081	3.811	9.567	0.842	231.918	113.639
5	May 1 to June 23, 1924	0.032	0.563	N.S.	N.S.	4.452	0.068	0.841	0.443	2.734	0 376	85.630	29.670
	June 23 to July 31, 1924	Absent	0.049	Absent	0.036	2.392	Trace	0.107	0.070	2.273	0.149	31.542	17.259
	August 1 to October 31, 1924	N.S.	N.S.	Absent	0.056	2.652	0.028	0.577	1.132	2.610	0.317	42.907	22.157
	November 1, 1924 to April 30, 1925	0.033	0.759	0.009	0.208	9.122	2.017	Trace	0 247	8.550	0.390	117.120	63.766
	Total	0.065	1.371	0.009	0.300	18.618	2.113	1.525	1.892	16.167	1.232	277.199	132.852
6	May 1 to June 23, 1924	0.011	0.011	N.S.	N.S.	2.182	Trace	0.313	0.116	1.493	0.201	61.033	28.616
	June 24 to July 31, 1924	Absent	0.039	N.S.	N.S.	1.433	0.033	0.506	0.351	0.997	0 056	18.966	10.303
	August 1, 1924 to April 30, 1925	0.527	0.615	Absent	0.148	12.686	0.243	0.432	0.137	7.192	0.127	86.810	43.732
	Total	0.538	0.665		0.148	16.301	0.276	1.251	0.604	9.682	0.384	166.809	82.651
7	May 1 to June 23, 1924	Absent	0.567	N.S.	N.S.	5.220	0.234	0.559	0.408	3.075	0.227	82.348	34.374
	June 24 to July 31, 1924	Absent	0.230	Absent	0.078	1.961	0.156	0.117	0.150	1.778	0.139	26.469	16.160
	August 1 to October 31, 1924	N.S.	N.S.	0.009	0.123	1.875	1.594	0.784	1.048	6.709	0.106	46.733	34.539
	November 1, 1924 to April 30, 1925	Absent	0.503	0.030	0.122	8.800	0.024	0.158	Trace	4.114	0.146	109.547	59.642
	Total		1.300	0.039	0.323	17.856	2.008	1.618	1.606	15.676	0.618	265.097	144.715

* N.S. = no sample.

TABLE 3

Summary of the annual loss of various chemical elements in runoff water from the different treatments

Pounds per acre

PLOT	TREATMENT	N AS NH_3	N AS ORGANIC	N AS NO_2	N AS NO_3	Ca	Mg	K	Na	S	P
1	Soybeans	0.172	2.821	0.0001	0.132	15.356	0.500	2.299	2.457	11.465	2.776
2	Spaded 4 inches		2.003	0.008	0.221	26.132	2.626	7.747	5.794	26.506	1.156
3	Spaded 8 inches	0.168	2.070	0.001	0.050	23.186	1.219	5.512	3.770	22.338	1.447
4	Sod		0.368			11.483	0.219	9.081	3.811	9.567	0.842
5	Wheat	0.065	1.371	0.009	0.300	18.618	2.113	1.525	1.892	16.167	1.232
6	Wheat followed by clover	0.538	0.665		0.148	16.301	0.276	1.251	0.604	9.682	0.384
7	Corn		1.300	0.039	0.323	17.856	2.008	1.618	1.606	15.676	0.618

TABLE 4

Annual loss of plant-food elements in the eroded soil from the various treatments

September 1, 1920, to August 31, 1922 (2, p. 38–40)

PLOT	TREATMENT	N	P	Ca*	S*
1	Not cultivated†	98.8	47.40	379.3	100.8
2	Spaded 4 inches fallowed	95.4	45.40	337.8	69.6
3	Spaded 8 inches fallowed	73.8	33.20	225.6	63.6
4	Sod	0.5	0.09	0.6	
5	Wheat annually	29.5	10.80	75.9	19.3
6	Corn, wheat, and clover	5.9	2.20	41.4	6.9
7	Corn annually	40.3	8.10	103.3	25.3

* One year's results.

† During the first 6 years of these experiments, plot 1 was uncultivated and uncropped. The land was kept bare by pulling the weeds.

TABLE 5

Loss of total soluble salts from plots with different treatments

Pounds per acre

PLOT	TREATMENT	SOIL ERODED MAY 1, 1924 TO APRIL 30, 1925	TOTAL SOLUBLE SALTS, 103°C.	SOLID MATERIAL	TOTAL SALTS AFTER IGNITION	SOLID MATERIAL	LOSS IN WEIGHT OF SALT BY IGNITION
				per cent		*per cent*	*per cent*
1	Soybeans	37190	249.9	0.67	101.7	0.27	59.3
2	Spaded 4 inches. Fallowed	89297	380.1	0.42	217.6	0.24	42.7
3	Spaded 8 inches. Fallowed	93728	309.1	0.33	169.7	0.18	45.1
4	Sod	388	231.9	59.76	113.6	29.28	51.0
5	Wheat	47694	277.2	0.58	132.8	0.28	52.1
6	Wheat and clover	2396	166.8	6.96	82.6	3.45	50.5
7	Corn	40326	265.1	0.66	144.7	0.36	45.4

salts coming from plots 2 and 3, which are fallow, or from plot 7, which is cultivated and has no winter cover crop, contain a larger percentage of inorganic salts than those carrying a crop the greater part of the year. The loss on ignition from plot 1, having soybeans followed by rye, is somewhat higher than that from the sod plots. No satisfactory reason has been found for this difference, since it would seem that it should fall intermediate between the corn land and the sod land.

SUMMARY

1. The runoff water from the soil erosion plots at the Missouri Experiment Station was sampled after each rain during the year May 1, 1924 to April 30, 1925. This water was passed through clay filters and the amount and composition of the soluble salts were determined on aliquot samples.
2. The total amount of dry salts lost varied from 166.8 pounds from the plot in wheat and clover to 380.1 pounds per acre from the plot which was spaded 4 inches deep in the spring and fallowed throughout the season.
3. Calcium and sulfur were lost in larger amounts than any of the other elements determined. The loss of potassium was relatively small but from several of the plots it amounted to considerably more than would ordinarily be applied in commercial fertilizer. The losses of magnesium, sodium, and phosphorus are too small to be of much practical importance.
4. The nitrogen determinations were incomplete on some of the samples, but these results as well as others reported earlier indicate that the surface runoff water is not a great source of nitrogen loss.
5. The soluble salts from the fallow plots showed a higher percentage of inorganic material, as indicated by a smaller loss on ignition, than did the soluble material coming from land carrying a crop.

REFERENCES

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THE MOISTURE EQUIVALENT OF SOILS

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A review of the literature on the Briggs-McLane method of determining the "moisture equivalent" of soils causes serious doubt as to the general correctness of those authors' original idea, that in this process "each soil loses water until the capillary forces have been increased sufficiently to balance the centrifugal force acting on the soil moisture" (3, p. 140) and that this so-called constant is "a single valued numerical expression of the moisture retentiveness of the soil measured in a definite way which establishes at once a relationship between this soil and any other soil whose moisture equivalent is known" (3, p. 145). Without denying the wide utility of the method for the purpose as outlined by Briggs and McLane, it is our intention in this paper to discuss the theoretical aspects and point out some limitations of the method.

It is significant to note that the numerous attempts (2, 7, 10) to correlate mechanical composition with the moisture equivalent have not been particularly successful. This may be due in part to the fact that the ordinary method of mechanical analysis does not give sufficient information about the clay fraction, but other factors are obviously involved as well. Indeed, the incentive for the present investigation was the observation that the finest textured horizon of a heavy clay profile gave the lowest moisture equivalent.

Middleton's data (7, p. 160) indicate that on the average, silt loam and silty clay-loam may retain nearly as much water in the moisture-equivalent machine as clay and considerably more than sandy clay, loam, or clay-loam, which are about equal in this respect. Evidently, the silt has an important water-retaining power. In the various equations for calculating the moisture-equivalent from the mechanical analysis the ratios of the coefficients of the silt and clay are as follows: Briggs and McLane, 0.2; Alway and Russel (1) 0.5; Middleton (equation 2), 0.68.

It is recognized that the soil structure may have a profound effect on the moisture-equivalent. Sharp and Waynick (9) have increased this value 50 per cent in the case of a clay-loam soil by treating with a normal solution of a sodium salt and subsequently washing with water. Calcium chloride was without effect. It is well known that the treatment with sodium salts as carried out by these authors produces an alkaline soil which has a "bad" physical condition and is very impermeable to water. Joseph and Hancock (5) propose the use of the moisture-equivalent method to determine the plasticity

of clay by making determinations under ordinary conditions and also after ignition as well as after saturating the unignited material with 3 per cent sodium carbonate instead of pure water.

It is evident therefore that, particularly in the case of fine-textured soils, the moisture-equivalent may be influenced to a greater extent by the arrangement and state of aggregation of the particles than by their size and distribution of size. It is evident also that the permeability of the sample is often an important factor which may preclude the attainment of a capillary equilibrium in any reasonable length of time. If a capillary equilibrium is not attained, the determination is without quantitative significance, though it may indicate qualitatively the impermeable nature of the material. This is an argument against the practice of arbitrarily making the time of centrifuging the same for all kinds of soil.

The senior author (11) has already proposed a partial solution of the problem of the capillary equilibrium by equating the "centrifugal" force to the capillary potential gradient. The question has been studied further by Veihmeyer and his coworkers (13) who have considered in detail the distribution of the moisture and the apparent specific gravity of the soil block. Russel and Burr (8) have recently determined the water retained when the speed of the machine is varied to correspond to forces ranging from 100 to 1400 times gravity. More information is now needed on the influence of the outer boundary and also on the relation between the size of the soil particles and the distribution of the water in the soil mass. Data on these questions are submitted in this paper.

EXPERIMENTAL

In the work reported below a standard machine was used which operated at 2410 to 2430 r.p.m. The following soils were studied:

T1. A very heavy calcareous Trenton clay.
G1. A fertile silty clay-loam from the Greenville Farm.
1170. Ballard Clay (0–11 inches)—a light clay nearly free from lime.
1170A. A separate from 1170 with all particles smaller than 2μ in diameter.
1171. Ballard Clay (11–15 inches)—a very heavy clay containing 2 per cent calcium carbonate, subsoil to 1170.
1286. Ramona clay-loam from La Habra, California, supplied by W. P. Kelley. This sample has been extensively studied by Dr. Kelley as Soil 431.

Separates from *G1* as follows: S.W. 5; S.W. 6; S.W. 7; and S.W. 9.

Separates from *T1* as follows: T0, T2, T3, T4, T5, T6, and T7. Also a mixture of T0 and T2.

The size-distribution curves of the first two soils and most of the separates have already been published (12, p. 5).

Amount of material centrifuged

It has been shown (8, 11, 13) that the percentage of water retained by a soil decreases as the amount of soil centrifuged increases, except in the case of

TABLE 1

Influence of the size of sample and time of centrifuging on the moisture-equivalent of the soil separates

SOIL NUMBER	SIZE LIMITS DIAMETER	WEIGHT OF SAMPLE	TIME	MOISTURE EQUIVALENT		WEIGHT OF SAMPLE	TIME	MOISTURE EQUIVALENT	
	μ	*gm.*	*hours*	*per cent*	*per cent*	*gm.*	*hours*	*per cent*	*per cent*
S.W.5	40–90	25.0	1.0	5.4	4.1	60	1 0	3.7	....
S.W.6	30–80	26.0	1.0	7.0	8.0	..	...	. ..	....
S.W.7	28–60	26.0	1.0	8.6	8.6	..	..	... .	. ..
S.W.9	16–40	5.0	1.0	32.3	32.1	31	1.0	10.1	11.4
		10 0	1.0	26.7	27.4	35	3.5	10.2	12.3
		20.0	1.0	15 4	16.6	40	1.0	10.1	9.8
		25 0	1.0	12.4	16.1	70	2.0	6.9	7.5
		25.0	2.0	13.3	....	70	3.5	5.5	8.1
T0	12–22	17.5	2.0	37.3	....	..	...	....	....
T0 + T2	5–22	5.0	2 0	44.7	41.8	25	3 5	32.4	....
		10 0	0.5	46.1	46.3	..	...	....	....
T2	5–12	10 0	0.5	40.2	40.7	25	3.5	36.2	....
		25.0	2 0	34.4	....	..	...	....	....
T3	4.4– 9	5.0	0 5	35.0	34.0	25	2.0	33.2	32.6
		10.0	0.5	32.8	34.2	40	3.5	31.2	30.2
T4	2– 5	5.0	0.5	38.7	38.6	24	2.0	39.7	39.6
		5.0	1.0	38.4	39.4	24	3.5	38.1	37.3
		5.0	3 0	39.1	38.1	35	2.0	38.3	38.5
		10.0	0.5	39.0	37.9	35	8.7	36.2	36.6
		10.0	2.0	37.8	38.1	50	2.0	37.6	37.1
		17.0	2.0	38.5	....	50	8.7	34.6	37.1
T5	1– 3	5.0	0.5	42.8	42.3	10	3.5	42.7	40.1
		5.0	1.0	41.5	42.3	20	2.0	43.8	44.4
		5.0	2.0	41.6	43.4	20	3.5	41.6	41.0
		10.0	0.5	43.1	43.5	30	3.5	40.3	41.0
		10.0	1.0	43.7	42.3	50	2.0	42.5	42.8
		10.0	2.0	43.4	43.8	50	8.7	40.6	40.6
T6	Smaller than 1.0	25.0	2.0	50.1	49.5	..	...	....	....
T7	Smaller than 0.5	25.0	2 0	60.4	61.3	..	...	....	....

impermeable materials, which do not permit the ready passage of water through the larger samples. These observations are confirmed by the data presented in tables 1 and 2, which show the influence of the amount of sample and the time of centrifuging on the water retained by the soil separates and by the Trenton clay respectively. It will be seen that the amount of material centrifuged has a marked effect in the case of separate S.W.9, but a very slight effect on the finer silts, T4 and T5, and also on the coarser separate S.W.5. When the size of the sample is increased, Trenton clay shows first a decrease then an increase in the amount of water retained after two hours, but a longer period in the centrifuge reduces the water content of the larger blocks to about 28 per cent. It was observed that the samples which were drier than 28 per cent contained radial cracks due to shrinkage and this final reduction of the moisture content was therefore accomplished by evaporation,

TABLE 2

Influence of size of sample and time of centrifuging on the moisture-equivalent of Trenton Clay

WEIGHT OF SAMPLE	TIME	MOISTURE EQUIVALENT		WEIGHT OF SAMPLE	TIME	MOISTURE EQUIVALENT	
gm.	*hours*	*per cent*	*per cent*	*gm.*	*hours*	*per cent*	*per cent*
5	2.0	35.9	37.3	40	2.0	31.0	32.6
10	2.0	36.3	36.7	40	8.7	30.4	30.3
20	2.0	33.2	31.4	50	2.0	34.4	34.8
25	0.7	38.8	40.0	50	8.7	29.6	29.8
25	8.7	29.5	32.5	60	2.0	35.2	35.6
30	2.0	31.6	32.6	60	8.7	30.9	30.1
30	18.0	30.0	17.0*	60	18.5	25.8†	28.2
30	25.5	22.7*	25.5†	60	37.5	19.0*	27.6†
30	29.0	10.3*	....	60	48.5	19.3*	26.3†
30	40.0	26.3†	13.2*	60	54.5	17.0*	25.1*

* Large radial cracks had formed in the soil block and at least some sections of the block were nearly air-dry.

† Large radial cracks had formed in the soil block.

since air could then pass freely through the block of soil. This was indicated by the fact that frequently one detached portion of the soil block was nearly air-dry when other parts were very moist. Moreover, duplicate determinations varied widely in these drier samples, showing that the permeability to air was variable.

When the moisture equivalent of a definite amount of each soil separate is plotted against the average diameter (using a logarithmic size scale for convenience), a curve is obtained with a maximum at about 10μ and a minimum at about 5μ. (Fig. 1.) This effect is more noticeable in the 10-gm. samples than in the 25-gm. samples. It seems likely that the maximum represents a condition in which the pores are just small enought to remain completely filled with water, and in which the packing of the solid particles is less dense than in the case of the finer separates. Increasing the amount of material centrifuged

would then tend to obliterate the maximum because of the establishment of a moisture gradient in the soil as well as of closer packing.

Distribution of the Water

From theoretical considerations, it seems evident that the criterion for an equilibrium in which capillary forces balance the centrifugal force of the machine, is a decrease in the water content of the soil in the direction of the axis of rotation. This gradient is a function of the texture and manner of packing of the soil materials. It should be small in coarse sands, because the capillaries are so large that the centrifuge can easily throw out most of the water and we are dealing only with small water wedges at the points of con-

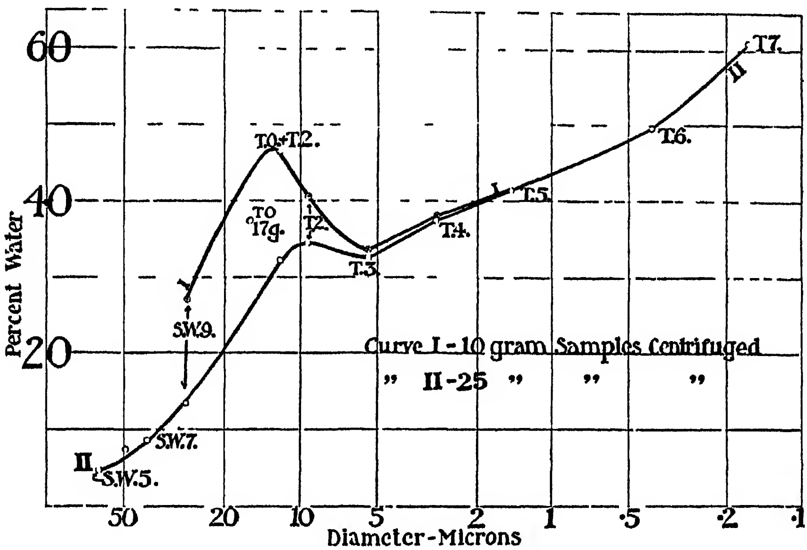

FIG. 1. MOISTURE RETAINED BY THE SOIL SEPARATES

The abscissa represents the average size of the particles of each separate, on a logarithmic scale.

tact of the solid particles. On the other hand, the largest capillary spaces of very fine textured soils may be so small that the centrifuge is unable to empty them and in this case there will be a nearly uniform distribution of the moisture at equilibrium. Between these extremes, it should be possible to realize a large gradient.

The moisture distribution in the centrifuged soil mass was found by cutting the block into several pieces, perpendicular to the radius of the machine, and drying each portion separately. This division in some cases was made roughly by means of a spatula; in others, exactly by the use of the slicing device described by Veihmeyer et al (13, p. 19–24).[1]

[1] This apparatus was very kindly lent to us by Prof. Frank Adams, University of California.

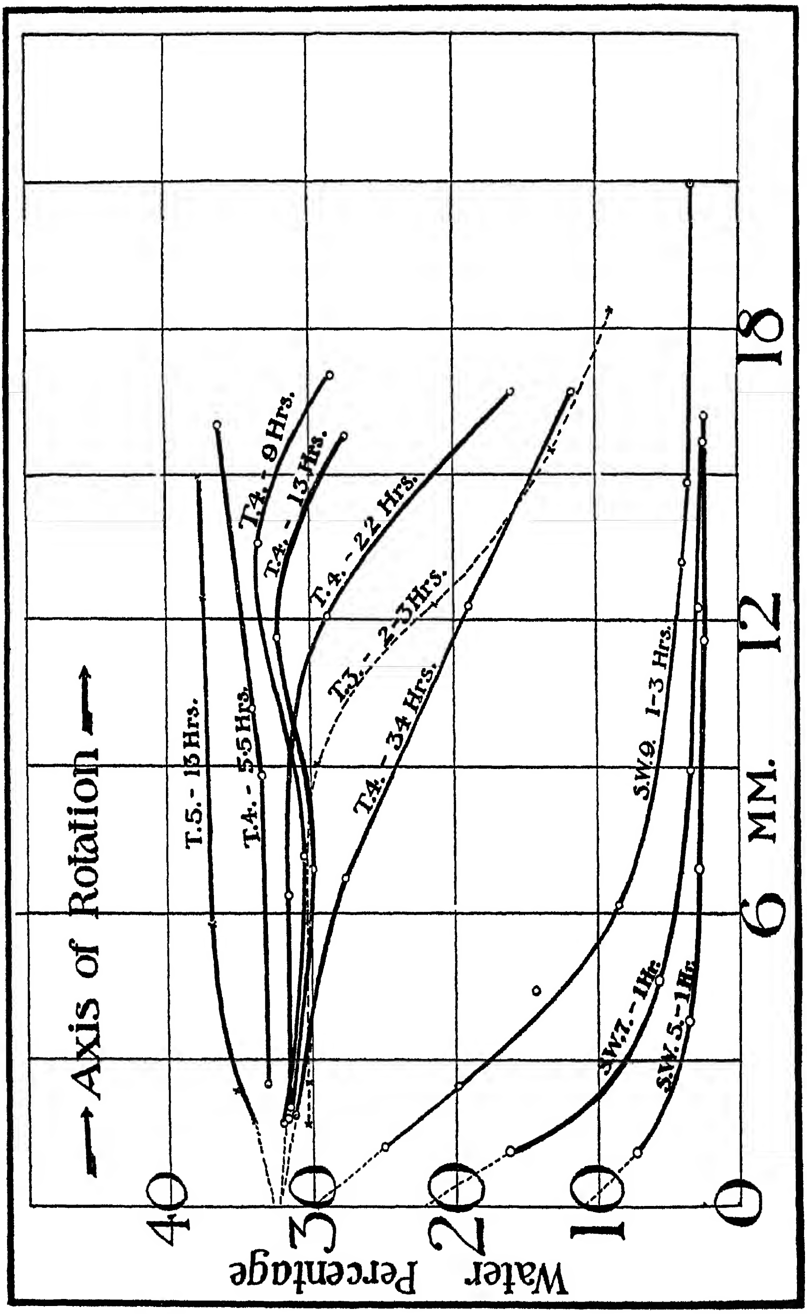

Fig. 2. Distribution of Water in the Soil Separates after Centrifuging for Different Lengths of Time as Indicated on the Curves

The abscissa represents the distance from the outside boundary

The data for the soil separates are presented graphically in figure 2, and the results for Trenton clay are given in table 3. These data show:

(*a*) That the moisture gradient in soil S.W.5 is small.

(*b*) That a large moisture gradient is readily established in soil S.W.9; and that soil T3 behaves similarly but less readily.

(*c*) That the movement of water through soil T4 and soil T5 is so slow that it requires many hours for the excess of water to move from the inner surface to the outside boundary and establish a moisture gradient opposing the centrifugal force of the machine. The series of curves representing soil T4 depict this movement clearly; and a similar series might be drawn for soil T5. It should be emphasized that in these cases considerable difficulty would be encountered in arriving quantitatively at equilibrium because of the possibility of some evaporation taking place from the inside layers during the long exposure in the centrifuge.

TABLE 3

Distribution of the water in 60-gm. samples of Trenton clay

The blocks of soil were cut perpendicular to the radius of the machine. The first value represents the portion nearest the outside boundary.

TIME	THICKNESS OF SECTION	WEIGHT OF SECTION	WATER	TIME	THICKNESS OF SECTION	WEIGHT OF SECTION	WATER
hours	*mm.*	*gm.*	*per cent*	*hours*	*mm.*	*gm.*	*per cent*
2.0	....	15.7	30.8	8.7	3.75	12.6	28.3
	3.0	9.5	31.5		3.0	10.1	27.8
	3.0	9.7	32.7		3.0	10.1	28.2
	3.0	9.9	34.2		3.0	8.9	28.0
	....	12.3	37.2		3.0	9.6	28.0
	....	....	....		....	7.0	28.5
18.5	....	10.1	24.4	18.5	....	13.2	28.6
	....	18.2	25.9		....	17.3	28.1
	....	18.1	26.2		....	15.8	28.2
	....	13.0	25.9		....	14.0	27.9
54.5	....	26.7	16.9	54.5	....	16.2	25.5
	....	14.7	16.9		....	22.5	25.1
	....	10.8	17.3		....	10.1	25.0
	....	7.6	17.0		....	11.5	24.9

(*d*) Trenton clay has an increasing moisture content toward the axis of rotation until it has been centrifuged long enough to establish a uniform distribution at about 28 per cent of water. Subsequent drying, due to cracking and evaporation, does not alter this uniform distribution.

(*e*) With the fine textured soils, many hours of centrifuging are required approximately to establish equilibrium.

The influence of texture on the moisture distribution, as described above, can be inferred from the results of Russel and Burr (8). When these authors plotted the amount of moisture, M, retained against the centrifugal force, G,

they obtained a family of curves, parabolic in form, which could be expressed by the equation:

$$M = \frac{K}{G^n}$$

where K and n are constants which decrease in value (except for the coarsest material) as the texture becomes finer. As the value of n determines the shape of the curves, it is clear that as the texture becomes finer (except for the coarsest sand) there will be a decrease in the influence of changing the speed of the machine on the amount of water retained.

It may be pointed out that the moisture gradient as found in the centrifugal machine should be one thousand times as great as in the gravitational field. Useful information could readily be obtained from capillary potential studies if the equilibrium moisture gradient under field conditions could be calculated from moisture equivalent data. Data are available for this comparison in the case of the Greenville soil. From figure 3 it may be estimated that the moisture gradient of this soil (containing about 18 per cent of water) under the influence of gravity should be 0.08 per cent per foot. Israelsen (4, fig. 15) has actually found by a study of this soil in the field a value of 0.14 per cent per foot in the case of the uniform-textured upper 4 feet of plat B (4, fig. 13). In this work, field plats were given heavy irrigations, then covered with straw to prevent evaporation, and sampled at intervals for several months until equilibrium was reached. This agreement is fairly good in view of the fact that the two cases are probably not strictly comparable, because of differences in packing. The gradient, as determined for all the data in his figure 15, is 0.35 per cent per foot, but as these data involve a correction for texture which is admittedly an approximation it seems best to make the above comparison on the basis of uniform-textured soil.

The apparent specific gravity

Veihmeyer and coworkers (12) have determined the apparent specific gravity of their soils after centrifuging. They show that the compaction increases somewhat with increasing weight of soil used, and that within a 60-gm. sample the apparent density increases for about 6 mm. from the inside surface, beyond which it remains nearly constant. We have made a few calculations of the apparent specific gravity of our soils from data obtained by the slice-weight method (13, p. 24). The values presented in table 4 are the averages of several determinations in most cases. The paraffin method was unsatisfactory because there was a tendency for the hydrocarbon to penetrate the soil.

It will be seen that the Trenton separates are less compact than the other soils and also that their pores are nearly completely filled with water. An explanation is thus afforded for the high water retaining power of the fine silts as compared with heavy clay: the capillary spaces which the centrifuge is

unable to empty are occupied entirely with water in the silt whereas part of the corresponding space in the clay is occupied by colloidal particles.

The outside boundary

Considerable theoretical interest is attached to the outside boundary. If the moisture percentage at this point is varied, changes should be reflected throughout the remainder of the soil mass. The capillary potential gradient should remain unchanged but the moisture gradient should probably decrease as the outside surface becomes drier. This follows from the fact that the capillary potential-moisture curve for soil appears to be a rectangular hyperbola (11).

The question was studied experimentally as follows:

A number of different kinds of filter paper boundaries were first tried using Greenville soil. No significant changes in the moisture equivalent were observed. Boundaries were next constructed using 5-gm. samples (1.6 mm. thick) of the different soil separates. These were retained in the cup and also by means of two filter papers were separated from the 60-gm. samples of Greenville soil placed on top. Four periods of centrifuging were employed: 2, 5½, 7, and 16 hours. The soil was dried in layers.

TABLE 4

Degree of packing and water retaining power of the soils

SOIL NUMBER	WEIGHT OF SOIL USED	SPECIFIC GRAVITY		WATER RETAINED BY		WATER REQUIRED TO FILL PORE SPACE
		Real	Apparent	Entire soil mass	Outer layer	
	gm.			*per cent*	*per cent*	*per cent*
S.W.5	60	2.72	1.40	3.7	8.4	34.6
S.W.9	60	2.72	1.40	9.5	32.3	34.6
T3	60	2.72	1.28	23.0	30.8	40.1
T4	60	2.72	1.32	32.0	33.0	39.0
T5	60	2.72	1.36	35.7	36.5	36.7
G1	60	2.75	1.46	18.3	21.3	32.0
T1	60	2.77	1.40	28.1	28.5	35.3

The two intermediate periods gave closely agreeing results; but two hours was not sufficient to establish equilibrium and 16 hours seemed to permit some evaporation. The data presented in figure 3 are the averages of the two intermediate periods and show the distribution of the water in the Greenville soil when the boundary material was that indicated on the curve. It will be seen that soil S.W.9 increases the amount of water retained by the Greenville soil above that shown by one piece of filter paper, whereas the Trenton separates cause a decrease which is greater the finer the separate. The sandy separate S.W.5 also causes a decrease and behaves in an anomalous fashion. The other curves are all nearly parallel and seem to indicate that the gradient is nearly constant over this range, the position of the curve depending on the outside boundary. However, the moisture gradient in the wetter soils is some-

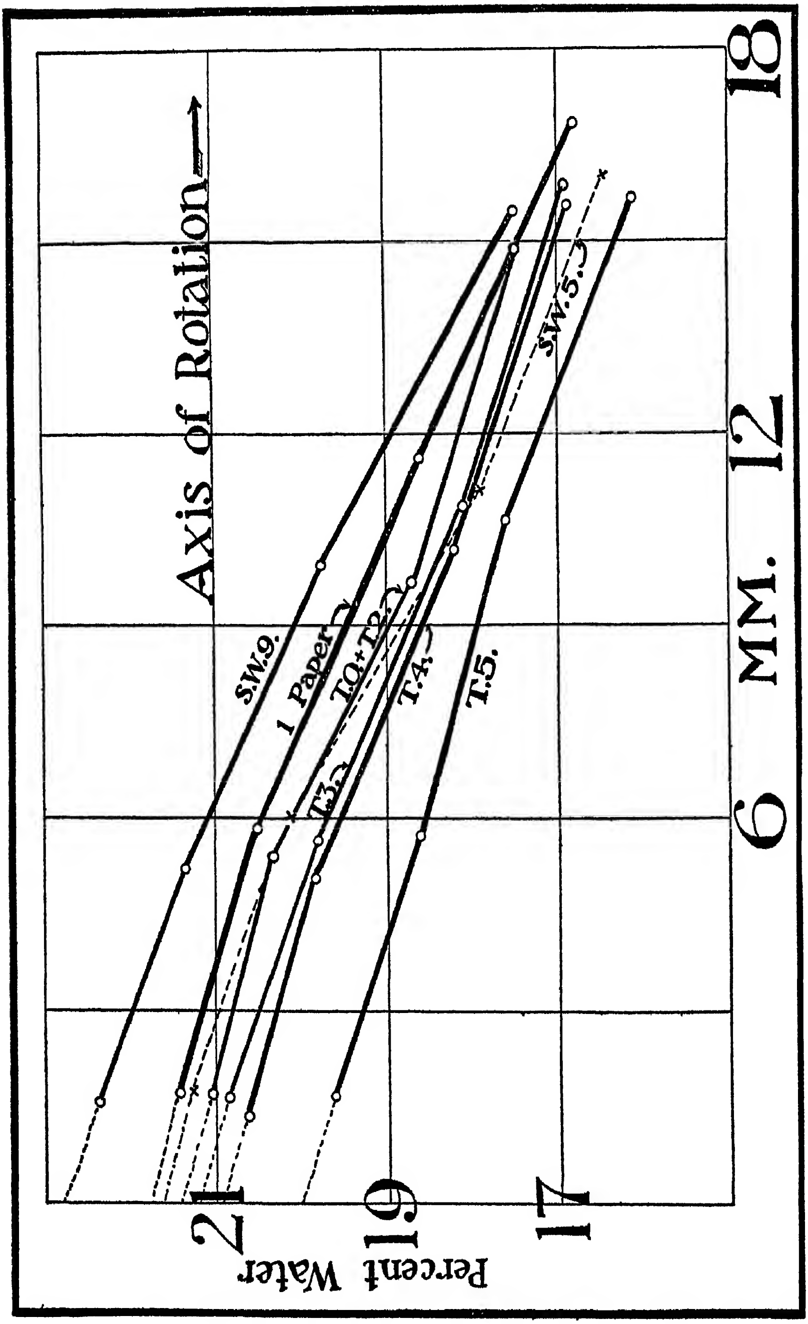

FIG. 3 DISTRIBUTION OF WATER IN THE GREENVILLE SOIL (G1) AFTER CENTRIFUGING 5.5 TO 7 HOURS, USING OUTSIDE BOUNDARY MATERIALS AS INDICATED IN THE CURVES

The abscissa represents the distance from the outside boundary

what greater than in the drier soils. It is suggested that the water in the outer layers of the Greenville soils is in capillary equilibrium with the water in the separate which acts as a boundary, and therefore, the negative curvature of the water wedges in the soil will be increased, with a corresponding decrease in the moisture content, as the size of the capillaries in the outer surface is reduced. No attempt is made to explain the behavior of S.W.5, further than to state that after 2 hours centrifuging, this material gave a distribution identical with that shown in figure 3 for S.W.9.

These data can be studied quantitatively through the following thermodynamic relations:

$$ln \frac{P_0}{P_1} = \frac{Mgh}{RT} \qquad (A)$$

$$ln \frac{P_0}{P_1} = \frac{M}{RT}\frac{2t}{r} \qquad (B)$$

In these equations P_1 is the vapor pressure at height h above a flat water surface of vapor pressure P_0, in equilibrium with a water surface having a negative radius of curvature r, and t is the surface tension of water. The vapor pressure lowering in the gravitational field g at constant temperature, according to equation A, is 0.0072 per cent per meter of elevation above a flat water surface. In the centrifugal field of the moisture equivalent machine, this value is 0.0072 per cent per millimeter, at least over a small range, in the direction of the axis of rotation. Equations connecting the vapor pressure and capillary potential functions have already been published (11).

In figure 3, it may be seen that the outside layer of the Greenville soil having T5 as the boundary material has the same moisture content as the layer 9 mm. within the soil mass when S.W.9 is the boundary material. The outside layer of the former sample of Greenville soil should therefore have a vapor pressure 0.065 per cent lower than the outside layer of the latter. It remains now to determine whether this difference can be accounted for by the difference in size of the capillary spaces of the two separates. Since the pore space of both T5 and S.W.9 is about 50 per cent (table 4) the average size of the capillary spaces in each case is probably equal to the average size of the soil particles, viz., 0.9 and 13μ radius. If we substitute these values of r in equation B, we obtain vapor pressure lowerings of 0.116 per cent and 0.008 per cent respectively. The value of r which corresponds to a vapor pressure lowering of 0.065 per cent + 0.008 per cent[2] is 1.4μ.

Table 5 shows the results of this calculation for the data of figure 3. The soil separates were practically saturated with water in each case.

The agreement of the vapor pressure values calculated by the two independent methods is satisfactory, considering the uncertainty connected with the

[2] This addition of 0.008 per cent is made because the calculation is referred to the capillaries of soil S.W.9 instead of to a flat-water surface.

evalution of the size of the capillary spaces, and shows quantitative conformation to the theory of capillary equilibrium.

Base replacement

Five clay soils, three of which were highly colloidal, were treated repeatedly with normal solutions of the chlorides of ammonium, sodium, potassium, calcium, and aluminum, as well as 0.05 N hydrochloric acid, and subsequently washed free of soluble material. The soil was then air-dried and moisture equivalent determinations were made on 20-gm. portions, centrifuging for 40 minutes. The results are given in table 6, which shows a marked increase of moisture retention as a result of the sodium treatment. The other bases behave nearly alike although ammonium and potassium have a slight tendency to increase the moisture retention. The low value obtained with the natural soil 1171 is probably due to the presence of 1 per cent of soluble salt

TABLE 5

Influence of the size of the capillary spaces in the boundary material on the vapor pressure of the adjacent layer of the Greenville soil

BOUNDARY MATERIAL				ADJACENT LAYER GREENVILLE SOIL	
Number	Size limits radius-microns by mechanical analysis	Average size of particles (or pores) radius-microns	Size of pores calculated from vapor pressure data (column a) radius-microns	Vapor pressure lowering: From equation A (+ 0.008) a	Vapor pressure lowering: From equation B b
				per cent	*per cent*
S.W.9	8–20	13.0	(13.0)	(0.008)	0.008
T0 + T2	2.5–11	5.0	3.0	0.038	0.021
T3	2.2–4.5	3.0	2.6	0.042	0.035
T4	1.0–2.5	1.6	1.9	0.057	0.065
T5	0.5–1.5	0.9	1.4	0.073	0.116

TABLE 6

Influence on the moisture-equivalent of treating the soil with various solutions and subsequently washing out the soluble material

Time of centrifuging—45 minutes; weight of sample—20 gm.

SOIL NUMBER	MOISTURE EQUIVALENT AFTER TREATMENT: Natural soil	Washed with H_2O	N $AlCl_3$	N $CaCl_2$	0.05 N HCl	N KCl	N NH_4Cl	N NaCl
1170	32.9	32.5	....	36.0	34.1	35.1	34.6	40.6
1170A	....	53.3	50.7	53.7	51.2	65.9	67.6	75.5
1171	42.0	51.7	....	47.7	47.9	50.0	50.8	69.2
1286	34.4	....	37.4	38.5	36.5	37.7	39.5	82.7
T1	39.4	....	....	38.8	....	40.3	41.7	60.0

in the sample. The sodium-treated soils were very impermeable and some free water was usually present inside the cup. Sufficient material was not available for a detailed study of these effects. It is unlikely that equilibrium was attained in any case. The results are therefore a measure of the comparative permeability, as influenced by the degree of swelling of the colloids. Since soil colloids possess elastic properties the sodium-saturated compounds would probably be more swollen and retain more water at equilibrium than the others. This does not necessarily prove that its "internal surface is greater" as suggested by Sharp and Waynick (9). The data suggest the importance of a consideration of soil structure in comparing results obtained by the moisture equivalent method, particularly in the case of fine-textured soils.

SUMMARY

A study of the moisture equivalent method as it is influenced by the amount of material centrifuged; by the texture and chemical treatment of the soil; and by the nature of the outside boundary, leads to the following conclusions:

1. Increasing the size of sample reduces to a slight extent the amount of water retained in very coarse and very fine soils, whereas soils of intermediate texture show greater effects.
2. The moisture gradient in the soil mass, opposing the centrifugal force of the machine shows a similar maximum with intermediate textures. Very fine grained soils have a nearly uniform moisture distribution at equilibrium.
3. A period of many hours centrifuging is often required to establish capillary equilibrium in the case of heavy clays and very fine silts. The slow movement of water through a silt is shown graphically.
4. When 10- to 25-gm. samples are centrifuged, silt of about 10μ average diameter retains more water than silt of 5μ average diameter. This excess of water decreases with the increasing size of the sample.
5. The very fine silts have a lower apparent specific gravity than the heavy Trenton clay, and also retain as much or more water. It is suggested that the capillaries in the silt which the centrifuge is unable to empty are filled entirely with water, whereas in the clay the corresponding interstices contain some colloidal material.
6. As the capillaries of the outside boundary are reduced in size, the adjacent soil becomes drier and this reduction in the moisture content is reflected throughout the whole soil block. This effect conforms quantitatively to the thermodynamic theory of capillary equilibrium.
7. When the replaceable base of a clay is entirely sodium the impermeability, and probably also the equilibrium moisture retaining power, are greater than when the replaceable base is potassium, ammonium, calcium, aluminum, or hydrogen. The colloidal swelling is enhanced by the sodium in the complex.

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THE INFLUENCE OF LIME AND PHOSPHATIC FERTILIZERS ON THE PHOSPHORUS CONTENT OF THE SOIL SOLUTION AND OF SOIL EXTRACTS[1]

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The influence of lime on the solubility of phosphorus in the soil, both native and that added in different forms of phosphatic fertilizer, has been studied by a number of investigators. Ames and Schollenberger (1) have given a summary of the literature on the subject showing the varied results that have been secured by different workers. A study of these experiments indicates that in many instances the methods used were inadequate or not well adapted to the investigation, but in recent years new methods of soil investigation have been suggested that seem to be well adapted for use in a study of this problem.

In previous work the solubility of the soil phosphorus has been studied by means of extraction with dilute acid or water. Although such studies are valuable it seems very desirable to obtain data on the phosphorus content of the soil solution also. Recently Parker (13) and Burd and Martin (6) have made a study of the soil solution obtained by the displacement method. Their results show that the true soil solution is obtained by displacement. With the use of the procedure recommended by Burd and Martin sufficient soil solution for analysis can readily be obtained from most soils.

Preliminary studies showed that the phosphorus content of the soil solution was so low that the usual methods of determining phosphorus were of little value. A method for determining phosphorus in the soil solution should be very sensitive, capable of determining at least 0.05 p.p.m. PO_4 in the solution. Such a method has recently been used by Atkins (2) in the determination of phosphorus in soil extracts. A study of the method in this laboratory (14) shows that it is simple, rapid, and accurate. A very similar method has been used extensively by biological chemists (3). The method makes possible the determination of phosphorus in 100 cc. of solution containing only 0.02 p.p.m. PO_4. As it has many advantages over the older colorimetric method for determining phosphorus it was used in the present investigation.

It has been customary to prepare water extracts of soils by filtering them through Pasteur-Chamberland filters. Apparently in none of the work reported has a careful study been made of the influence of the filter on the phos-

[1] Published with the permission of the Director of the Alabama Agricultural Experiment Station.

phorus content of the soil extract. However, recent work in this laboratory (14) has shown that Pasteur-Chamberland filters absorb or give up phosphorus depending upon the relation between the degree of saturation of the filter and the phosphate concentration of the solution being filtered. Since the filter may materially alter the phosphate content of the solution it is probable that most of the data on the phosphorus content of soil extracts are of doubtful value. Consequently, the use of that method has been discontinued and another procedure adopted. In the present investigation all extracts were prepared by dialysis through collodion sacks. The detailed procedure will be given later.

Having the aforementioned methods in mind, the investigation was undertaken to determine the following: (*a*) the influence of lime on the phosphorus content of the soil solution and soil extracts from soils which have never received phosphatic fertilizer; (*b*) the influence of lime on the phosphorus content of the soil solution and soil extracts from soils fertilized with different phosphatic fertilizers; and (*c*) the influence of lime and different phosphatic fertilizers on the solubility of soil phosphorus. The solubility is indicated by a comparison of the concentration of phosphate in the soil solution and in soil extracts. The results also afford a comparison of the influence of different sources of phosphorus on the phosphate content of the soil solution and soil extracts. The sources of phosphorus studied include steamed bone meal, acid phosphate, rock phosphate, and basic slag.

METHODS

The soils used in this investigation were taken from experimental plots in Alabama, Ohio, Illinois, and Kentucky.[2] In all instances approximately twenty-five-pound samples of the surface soil were secured from each plot. On reaching the laboratory the soil was screened and placed in earthenware jars and brought to the moisture content considered most satisfactory for displacement—this varied from 10 per cent in the sandy soils to 25 per cent in one heavy soil. After their contents were mixed again the jars were covered to prevent evaporation until the soil solution was displaced.

The displacement procedure was essentially that used by Burd and Martin (6). A definite amount of soil at a known moisture content was packed in the displacement cylinders. Water was added and displacement was made under an air pressure of 15 to 20 pounds to the square inch. Successive 100- or 200-cc. portions of the displaced solution were obtained and used in subsequent work.

The first portion of the displaced solution is the true soil solution undiluted by the displacing liquid. In the second and successive portions the soil

[2] The authors wish to express their appreciation to Dr. F. C. Bauer for furnishing the samples from the Illinois plots, to Prof. A. W. Ames for furnishing the samples from the Ohio plots, and to Prof. George Roberts for furnishing the samples from the Kentucky plot.

solution becomes more and more diluted by the displacing liquid. This dilution is indicated by a gradual decrease in the calcium content and by an increase in the specific resistance of the successive portions. The specific resistance and the calcium and phosphorus were determined in the different portions.

The displaced solution was usually clear, but preliminary work showed that often a small amount of material was in suspension. As this material could not be removed satisfactorily by centrifuging, all solutions were dialyzed through a collodion membrane. A 100-cc. portion of the solution was placed in each of two collodion sacks. These were then placed in 250-cc. beakers containing 100 cc. of distilled water. Conductivity determinations indicated that equilibrium between the inside and the outside solutions was established in 18 hours; at the end of that time the specific resistance of the two solutions was the same. After the solution stood for 18 to 21 hours the collodion sacks and contents were removed, the two 100-cc. portions of diffusate were combined, 50 cc. was used for the determination of calcium and 150 cc. was used for the determination of phosphorus. The 150 cc. is equivalent to 75 cc. of the original solution.

Calcium was determined by titration of the oxalate with 0.05 N $KMnO_4$. In determining phosphorus in the soil solution, by the procedure recommended by Parker (14), the solution was evaporated, and the residue was ignited and taken up with acid. In the case of soil extracts the determination was made on 100 cc. of the extract without evaporating.

The 1:5 soil extracts were prepared by placing 40 gm. of soil in a 150-cc. collodion sack and adding 100 cc. of water to the soil. The sack was then placed in a 250-cc. beaker containing 100 cc. of water. The contents of the sack were shaken three times a day and were allowed to stand about 24 hours. At the end of that time the specific resistance of the inside and outside solutions was the same. Phosphorus was determined in the 100 cc. of solution in the beaker, called "outside solution" or "diffusate."

EXPERIMENTAL RESULTS

Cullar's Rotation Field, Auburn, Alabama

Since 1910 these plots have carried a 3-year rotation of cotton, corn, and oats followed by cowpeas. Lime was applied to one-half of all plots in 1915 at the rate of 2 tons of ground limestone to the acre. The soil is Norfolk sandy loam, slightly acid to the Truog test.

The plots used in this study were carefully sampled June 18, 1925. The plot numbers and treatments are given in table 1. Plot 3 received 800 pounds of acid phosphate for each 3-year rotation. Plot 5 received 1600 pounds of rock phosphate for each rotation. Plots 2, 3, and 5 receive the same nitrogen and potassium fertilizers. Displacement was made from the soil at a moisture content of 10 per cent. Three kilos of moist soil was packed in each of two displacement cylinders and successive 100-cc. portions of the displaced solu-

tion were obtained. The portions from the duplicate cylinders were combined for the determination of specific resistance, and of calcium and phosphorus. Displacement and all determinations were made in triplicate. The results given in table 1 are the average of the three series of determinations.

Lime applied to this slightly acid soil in 1915 at the rate of 2 tons to the acre

TABLE 1

Specific resistance, parts per million PO_4 and Ca in successive 100-cc. portions of the displaced solution from soil with the treatments indicated

Soil from Cullars rotation, Auburn, Alabama

PLOT NUMBER	FERTILIZER TREATMENT	PO_4 CONTENT		Ca CONTENT		SPECIFIC RESISTANCE	
		No lime	Lime	No lime	Lime	No lime	Lime
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*ohms*	*ohms*
First portion of soil solution							
2	N, K	0.075	0.138	238	489	226	143
3	N, K, acid phosphate	0.260	0.420	492	753	113	89
4	None	0.206	0.267	228	468	312	206
5	N, K, rock phosphate	0.210	0.292	487	635	103	92
Second 100-cc. portion of displaced solution							
2	N, K	0.079	0.134	220	360	267	178
3	N, K, acid phosphate	0.220	0.455	371	588	145	109
4	None	0.193	0.302	200	371	370	254
5	N, K, rock phosphate	0.226	0.288	384	510	124	110
Third 100-cc. portion of displaced solution							
2	N, K	0.066	0.129	130	263	356	242
3	N, K, acid phosphate	0.197	0.374	261	430	198	145
4	None	0.188	0.306	144	290	471	292
5	N, K, rock phosphate	0.205	0.267	265	372	166	143
Fourth 100-cc. portion of displaced solution							
2	N, K	0.060	0.129	111	195	498	327
3	N, K, acid phosphate	0.191	0.448	188	315	266	196
4	None	0.146	0.279	112	198	626	447
5	N, K, acid phosphate	0.183	0.301	197	227	230	217

had a marked influence on the solubility of the soil phosphorus. In plots 2 and 3, liming increased the phosphorus content of the soil solution 83 and 61 per cent respectively. The increase due to liming was not so great in the case of plots 4 and 5. The differences in the phosphorus concentration of the soil solution due to fertilizer treatment were greater on the limed than on the unlimed

soil. However, those differences were not as great as might be expected from a consideration of the history of the plots. As subsequent data will indicate, the phosphorus concentration of the soil extracts from these plots shows much greater differences due to phosphatic fertilization than are indicated in table 1.

A comparison of the successive portions of the displaced solution shows the relative solubility of phosphorus and other constituents of the soil solution. The data for calcium and for specific resistance indicate that the fourth 100-cc. portion is approximately 40 per cent as concentrated as the first 100-cc. portion or the soil solution. However, the phosphate concentration in the first and fourth portions is not very different. The fourth portion from the unlimed soil contains on the average approximately 80 per cent as much phosphorus as the soil solution. The fourth portion from the limed soil contains, with one exception, more phosphorus than the first portion. This increase in the phosphorus concentration of the successive portions is probably due to the high solubility of the phosphate and to the marked reduction in the calcium content

TABLE 2

Phosphate content of soil solution and 1:5 water extracts of soil with the treatments indicated

Soil from Cullar's Rotation, Auburn, Alabama

PLOT NUMBER	FERTILIZER TREATMENT	PO_4 CONTENT			
		Soil solution		1:5 extract	
		No lime	Lime	No lime	Lime
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
2	N, K	0.075	0.138	0.036	0.042
3	N, K, acid phosphate	0.260	0.420	0.336	0.490
4	None	0.206	0.267	0.012	0.020
5	N, K, rock phosphate	0.210	0.292	0.204	0 256

of the portions. As has been stated by Burd and Martin (5) a high calcium content of the soil solution may depress the solubility of phosphorus. This point will be considered in greater detail in connection with other data.

The PO_4 content of 1:5 soil extracts was determined in order to obtain further data on the solubility of soil phosphorus as influenced by liming and phosphatic fertilization. The extracts were prepared as previously described using collodion sacks. Table 2 gives the PO_4 content of the soil solution and of the 1:5 soil extract.

As has already been indicated, the differences due to phosphorus fertilization are more marked in the soil extracts than in the soil solution. The 1:5 extract of plots 2 and 4 which do not receive phosphate fertilization was much lower in phosphorus than the soil solution from these plots. The extract from plot 5, receiving rock phosphate, had a slightly higher concentration of phosphorus than the soil solution from the same soil. This difference was even greater in

the acid phosphate plot, the extract containing 0.490 p.p.m. PO_4 whereas the soil solution contained only 0.336 p.p.m.

The results obtained from the study of this soil indicate that liming materially increases the phosphate content of the soil solution or soil extract. The data in table 2 show that the effect of lime is greater when acid phosphate is used as a source of phosphorus than when rock phosphate is the source of phosphorus. Fertilization with acid phosphate produced a higher concentration of phosphate in the soil solution and in the soil extract than fertilization with rock phosphate.

Experimental fields at Albertville and Jackson, Alabama

Studies similar to the above were made on samples secured from rotation experiments on the experimental fields at Jackson and at Albertville, Alabama. The experiments afford a comparison of acid phosphate, rock phosphate, and basic slag on limed and unlimed soil. These plots were started in 1916. The phosphate fertilization with basic slag and acid phosphate is equivalent to 480 pounds of acid phosphate for each 3-year rotation. Twice this amount of rock phosphate is used. One series of plots was limed in 1916 at the rate of 2 tons to the acre. There has been no lime applied since that time. The Jackson soil is a Greenville sandy loam whereas the Albertville soil is Dekalb fine sandy loam. Both soils are medium acid according to the Truog test.

The water-soluble phosphorus in the soils from both fields was very low. The maximum concentration of phosphate in the soil solution from the Albertville field was 0.05 p.p.m. PO_4. The minimum concentration was 0.02 p.p.m. In the soil extract the concentration varied from a trace, probably 0.01 p.p.m. or less, to 0.069 p.p.m. The differences due to the form of phosphatic fertilization were small. Liming caused on average increase of 71 per cent in the phosphorus concentration of the soil solution and of 65 per cent in the soil extract. The detailed results are not given because no great dependence can be placed on the results from individual plots when the phosphate concentration is so low. The data are similar to those obtained with other soils, indicating the influence of liming on the solubility of the phosphorus.

The maximum concentration of phosphorus in the soil solution from the Jackson soil was 0.075 p.p.m. from the lime basic slag plot. The minimum concentration was 0.042 p.p.m. from the unfertilized unlimed plot. As with the Albertville soil, liming increased the concentration of phosphorus in the soil solution. The results obtained from the study of these two soils show the concentration of phosphorus in the soil solution may be very low and yet crop growth may be satisfactory. The fertilized plots in these experiments produce good crops of cotton, corn, and oats.

Phosphate experiments, Odin, Illinois

This experiment, started in 1904, affords a comparison of four forms of phosphatic fertilizer on an acid soil, some plots receiving 1 ton and others 8

tons of limestone to the acre. The soil is a gray silt loam on tight clay. The plots receiving 1 ton of lime are medium in acidity and have an average pH value of about 5.0. Those that have received 8 tons of lime are not acid according to the Truog test and average about pH 6.65. The different sources of phosphate were applied on the basis of equal money values instead of chemically equivalent amounts. The different sources, however, carry approximately the same amount of P_2O_5 except in the case of rock phosphate. The total amount of each phosphatic fertilizer applied to date is given in table 3. Hopkins et al. (9, p. 459) give the average crop yields and details of fertilization.

TABLE 3

Specific resistance, parts per million PO_4 and Ca in the first and second 200-cc. portions of the displaced solution from soil with the treatments indicated

Soil from Odin, Illinois

PLOT NUMBER	PHOSPHATE TREATMENT	PO_4 CONTENT		Ca CONTENT		SPECIFIC RESISTANCE	
		1 ton lime	8 tons lime	1 ton lime	8 tons lime	1 ton lime	8 tons lime
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*ohms*	*ohms*
	First portion of soil solution						
1	Steamed bone meal, 4200 pounds...	0.400	0.360	350	441	249	318
2	None..........................	0.120	0.260	246	416	315	354
3	Acid phosphate, 7000 pounds.......	0.212	0.897	346	562	259	224
4	Rock phosphate, 14,000 pounds....	0.154	0 307	299	427	235	302
5	None..........................	0.075	0.142	176	384	416	314
6	Basic slag, 5250 pounds...........	0.300	0.985	466	376	190	350
	Second portion of displaced solution						
1	Steamed bone meal, 4200 pounds...	0.446	0.265	236	308	378	485
2	None..........................	0.080	0.236	178	237	470	560
3	Acid phosphate, 7000 pounds......	0.107	0.772	231	375	395	354
4	Rock phosphate, 14,000 pounds....	0.100	0.273	214	257	347	358
5	None..........................	0.049	0.152	124	260	610	445
6	Basic slag, 5250 pounds...........	0.245	1.045	265	244	296	550

Two experiments were carried out with this soil. The first consisted of a study of the displaced solution similar to that reported in table 1. The second was a study of the solubility of the soil phosphorus. The details of both experiments and the tabular results will be presented before discussing the results in detail.

For displacement, 2400 gm. of soil at a moisture content of 20 per cent were packed in the displacement cylinder. Two successive 200-cc. portions of the displaced solution were obtained from each cylinder. These were analyzed for phosphorus and calcium and the specific resistance was determined. Dis-

placement was in duplicate, the single determinations being made on different days. The results are given in table 3.

In the second experiment 40 gm. of soil was placed in a 150-cc. collodion sack, 100 cc. of water added and the sack placed in a 250-cc. beaker containing 100 cc. of distilled water. After 24 hours, the diffusate was removed and replaced with 100 cc. of distilled water; this process was repeated for 17 days. Each day the amount of phosphorus in the diffusate was determined. The soil was kept in suspension moderately well by hand shaking three times a day. The first day the solution removed was equivalent to a 1:5 extract; the second day it was theoretically equivalent to a 1:10 extract; the third day it was equivalent to a 1:20 extract. By removing one-half of the solution each day and replacing it with distilled water the proportion of water in the soil-water ratio would theoretically be doubled. Calculated on this basis the soil-water ratio on the seventeenth day would be 1:327,680; or if we assume that the initial extract contained 1.0 p.p.m. PO_4 and that no more phosphorus came into solution from the soil, then, according to the procedure followed, the diffusate on the seventeenth day would contain 0.000,015 p.p.m. PO_4. Such a calculation illustrates the degree to which the soil was washed by the dialyzing process. Considering the extent to which the soil was washed one would expect a considerable decrease in the phosphate concentration of the solution removed on successive days. The results of this experiment are given in table 4. The figures for the "no phosphate" plot are the average for the two unfertilized plots.

The results of these two experiments afford some interesting data relative to the influence of lime and of different phosphatic fertilizers on the phosphate content of the soil solution and of soil extracts. The data may be conveniently discussed by considering the influence of each form of phosphatic fertilizer on the behavior of phosphate in the soil. The several forms of phosphate will be considered in the order in which they appear in tables 3 and 4.

Steamed bone meal caused a higher concentration of phosphate in the soil solution and in the soil extracts from the light limed plots than any other form of phosphate. On the other hand the application of 8 tons of lime had a very marked depressing effect on the solubility of phosphate from steamed bone meal. This is most strikingly shown by a study of table 4. The phosphate content of the extract from the plot receiving 1 ton of limestone is consistently about 75 per cent higher than on the heavily limed plot. The reduced solubility of phosphorus in the bone meal plot due to heavy liming is also shown by comparing the phosphate content of the first and second portions of the displaced solutions. On the plot receiving 1 ton of lime the phosphorus content of the second portion was greater than that in the first portion or soil solution. This was the only plot in which that was true for the soil receiving the small amount of limestone. When the soil was heavily limed the phosphorus concentration of the solution from the bone meal plot decreased in the second

portion. The percentage decrease was greater than on any other plot receiving the same lime treatment.

It should be noted here that the phosphorus concentration of the extracts from all fertilized plots was considerably greater than the phosphorus concentration of the soil solution. Burd and Martin (5) have observed that in some instances the phosphorus concentration of the second, the third, or a later portion of the displaced solution is greater than of the first portion, the true soil solution. They attribute the increased solubility to a reduction of the salt content of the successive portions of the displaced solution. The salts, particularly those containing the calcium ion, would reduce the solubility of phosphates. That explanation is probably correct and serves to explain the differences in the phosphate concentration of the soil solution and soil extracts. To obtain a higher concentration of phosphorus in the extract than in the soil solution the presence in the soil of a considerable amount of readily soluble phosphate is essential. When the readily soluble phosphate is not present the phosphate content of the extract will generally be lower than that of the soil solution.

Apparently there are at least two factors determining the phosphorus concentration of the soil solution or extract. The first factor is the amount and nature of the phosphatic compounds in the soil. Readily soluble or readily hydrolyzed phosphorus compounds tend to produce a high concentration of phosphorus in the soil solution. Precipitated calcium phosphate is more soluble than iron and aluminum phosphates and consequently causes a higher phosphate content of the soil solution or extract. That is undoubtedly the reason liming increases the concentration of phosphorus in the soil solution from soils fertilized with acid phosphate. The second factor influencing the concentration of phosphorus is the amount and composition of salts in the soil solution or extract. A high concentration of calcium salts would depress the solubility of all forms of phosphorus in the soil. The first factor is doubtless the more important of the two. Thus liming the acid phosphate plot increased the concentration of phosphorus in the soil solution. At the same time the high calcium content of the soil solution of the limed plot had a depressing effect on the solubility of the phosphorus. This depression of the solubility is seen by comparing the phosphorus concentration of the soil solution given in table 3, and of the soil extract, table 4. However, the increased solubility resulting from the first factor was greater than the depression in solubility due to the second factor. The second factor, the calcium content of the soil solution, reduces phosphate solubility in both limed and unlimed soil.

A study of the data for calcium and for specific resistance, given in table 3, shows that there is no correlation between the calcium and the phosphorus content of the soil solution; neither is there a relation between the specific resistance and the calcium or phosphorus content. Plot 6, receiving basic slag is a striking illustration of this fact. The soil solution from the heavily

limed plot contains less calcium and has a greater resistance than the soil solution from the plot receiving the small application of lime. The phosphorus concentration of the solution, however, was increased 338 per cent by the heavy application of limestone.

The phosphorus concentration of the soil solution and of the extracts from the unfertilized plots was materially increased by heavy liming. This indicates that liming makes more available the native soil phosphorus as well as that added as acid phosphate or basic slag.

The beneficial influence of lime on phosphorus solubility was greater on the acid phosphate plot than on any other plot in the experiment. The heavy application of limestone increased the phosphorus concentration of the soil solution 420 per cent, and of the 1:5 extract, 750 per cent. As has been indicated this influence of lime can doubtless be attributed to the formation of calcium phosphates instead of iron and aluminum phosphates when the soluble phosphate reacts with the soil constituents.

Apparently, the availability of rock phosphate was not materially influenced by liming. The data in table 3 indicate an increased solubility due to the 8 tons of lime. The soil solution from the heavily limed plot contained 0.307 p.p.m. PO_4 compared with 0.154 p.p.m. from the plot receiving only 1 ton of lime. The data in table 4, on the other hand, indicate a depressed solubility due to liming. After the first day the phosphorus concentration of the extracts from the heavily limed plot was always less than that from the plot receiving 1 ton of lime. A large amount of evidence from field and greenhouse experiments indicates a depressed availability of the phosphorus of rock phosphate due to liming. The work on phosphorus solubility (table 4) indicates a considerably depressing effect but the work with the soil solution indicates an increased solubility due to lime.

The solubility of phosphorus in the basic slag plot is increased by liming to almost the same extent as that in the acid phosphate plot. Heavy liming increased the phosphorus content of the soil solution 338 per cent, and the phosphate concentration of the 1:5 extract, 1050 per cent. The maximum concentration of phosphorus in the extract was 2.24 p.p.m. PO_4 on the third day. On the same day the acid phosphate plot gave a maximum concentration of 3.0 p.p.m. PO_4 in the extract.

The results of these experiments are in accord with those of Prianishnikov (15), who found that lime depressed the assimilation of phosphorus from bone meal and from rock phosphate but either did not affect, or increased, the assimilation from acid phosphate. His experiments were in sand cultures with several crops as indicators of phosphorus assimilation.

The second experiment (table 4) shows the ability of the soil to renew the phosphorus content of the extract over a period of time. As has been indicated, the extract on the first day had a soil water ratio of 1:5. The proportion of water doubles on each succeeding day, giving a ratio of 1:20 on the third day, and 1:327,680 on the seventeenth day. A study of table 4 shows that the

maximum concentration of phosphorus was not found on the first day and in some instances not until the sixth day. Usually the maximum for the heavily limed plots was reached on the third day whereas the maximum for the lightly limed plots was reached on the sixth day. This increase in concentration after the first day may have been due to the reduction in the salt content of the extracts. Again, it may have been due to the fact that the soil remained in suspension somewhat better after the salt content was reduced. After reaching the maximum concentration the phosphorus concentration of the extracts gradually declined. The decrease in concentration was most rapid for the heavily limed acid phosphate and basic slag plots. In those plots the con-

TABLE 4

PO_4 content of the diffusate obtained on successive days from soil receiving the treatments indicated

Soil from Odin, Illinois.

PHOSPHATE AND LIME TREATMENT		PO_4 IN DIFFUSATE						
		First day*	Third day	Fifth day	Seventh day	Tenth day	Thirteenth day	Seventeenth day
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Bone meal	1 ton lime..........	1.200	1.480	1.520	1.280	1.160	0.960	0.720
	8 tons lime..........	0.700	0.840	0.760	0.700	0.680	0.560	.....
Acid phosphate	1 ton lime..........	0.370	0.600	0.700	0.680	0.700	0.620	0.500
	8 tons lime..........	2.800	3.000	2.400	2.000	1.920	1.600	1.160
Rock phosphate	1 ton lime..........	0.340	0.560	0.620	0.600	0.600	0.480	0.360
	8 tons lime..........	0.380	0.500	0.500	0.440	0.400	0.360	0.220
Basic slag	1 ton lime..........	0.200	0.340	0.340	0.480	0.420	0.400	0.280
	8 tons lime..........	2.100	2.240	2.240	1.720	1.520	1.240	0.820
No phosphate	1 ton lime..........	0.020	0.025	0.025	0.037	0.037	0.024	Trace
	8 tons lime..........	0.108	0.200	0.217	0.217	0.210	0.143	0.080

* The diffusate obtained the first day was equivalent to a 1:5 extract.

centration of the extract on the seventeenth day was less than one-half the concentration of the extract on the first day. When only 1 ton of lime was used with acid phosphate, rock phosphate, and basic slag, the phosphate concentration of the extract on the seventeenth day was greater than on the first day. It was, however, considerably lower than the maximum concentration of the sixth day. These three plots reached the maximum on the sixth day although that is not indicated in the table. Taken as a whole, the results indicate the remarkable ability of the soil to maintain a given concentration of phosphorus in the soil solution. The concentration maintained will vary a great deal from soil to soil but the phosphorus concentration in the soil solution

of one soil probably does not fluctuate a great deal. In this respect phosphorus differs from most of the other essential elements.

Fertility experiment, Toledo, Illinois

The plots, whose treatment is indicated in table 5, afford a comparison of the influence of liming on the native soil phosphorus and on phosphorus added in acid and rock phosphate. The soil is a gray silt loam on tight clay and is strongly acid by the Truog test. Hopkins et al. (9) give the detailed treatments and crop yields for these plots.

The soil was brought to a moisture content of 20 per cent for displacement. Displacement and the phosphorus determinations were made in duplicate. Table 5 gives the phosphate concentration of the soil solution and of the 1:5

TABLE 5

The phosphorus content of the soil solution and soil extracts from soil with the treatments indicated

Soil from Toledo, Illinois

PLOT NUMBER	TREATMENT	PO_4 CONTENT		
		Soil solution	1:5 extract	1:25 extract
		p.p.m.	*p.p.m.*	*p.p.m.*
301 N	L (2 tons)	0.142	Trace	Trace
301 S	None	0.050	Trace	Trace
306 S	R	0.039	Trace	Trace
307 S	R, L (8 tons)	0.433	Trace	Trace
305 N	R, AP (800 pounds)	0.050	0.120	0.120
306 N	R, RP (1 ton)	0.050	0.100	0.070
307 N	R, L (8 tons), AP (800 pounds)	0.445	0.400	0.200
308 N	R, L (8 tons), RP (4 tons)	0.373	0 090	0.045
309 S	R, L (8 tons), RP (tons), K	0.264	0.076	0.040

and 1:25 water extracts. The extracts were made in the usual manner, 21 hours being allowed for the system to come to equilibrium.

The results obtained with this soil confirm those already reported. In every instance liming materially increased the phosphorus content of the soil solution—in most cases, approximately 800 per cent. The results obtained with the extracts differ in several respects from those obtained with the soil solution. The extracts from all plots not receiving phosphatic fertilizers contained only a trace of phosphorus. Liming the unfertilized plot produced a large increase in the phosphorus content of the soil solution. However, the amount of readily soluble phosphorus must have been very low, for the extracts contained only a trace of phosphate. Liming materially increased the phosphate concentration of the extracts from the acid phosphate plots. The solubility of rock phosphate was apparently reduced by liming. The unlimed rock phosphate plot received only 1 ton of rock phosphate whereas the limed

plot received 4 tons. In spite of this higher rate of fertilization the extracts from the limed plots contained less phosphorus than the extracts from the unlimed plot. This is similar to the results obtained on the soil from the Odin field.

A study very similar to that made on the Toledo field was also made on soil from the Aledo, Illinois, field. The soil treatments were almost identical with those of the Toledo field. The soil is a strongly acid black clay loam. As considerable difficulty was experienced in displacing the soil solution, the results obtained for some plots are not very dependable. However, the results are similar to those obtained from the Toledo field except that the phosphorus concentration of the solution and of the extracts was lower and the influence of liming was not as great.

Wooster, Ohio and Berea, Kentucky soils

The soil solution from the limed and unlimed halves to plots 10 and 11 of the 5-year rotation at Wooster was obtained and the concentration of phosphorus determined. Considerable difficulty was experienced in obtaining the soil solution by displacement; consequently, the results are for single determinations and are therefore subject to error. Liming did not influence the concentration of phosphorus in the soil solution of the unfertilized plot, the concentration in both the limed and unlimed soil being 0.12 p.p.m. PO_4. The phosphate concentration of the solution from the fertilized plot was 0.13 p.p.m. in the unlimed soil and 0.18 p.p.m. in the limed soil. The extracts from these soils did not contain a determinable amount of phosphorus after the soil had been in the water 8 days.

Studies similar to the above were made on soil from seven plots from the Berea, Kentucky field (16). The water extracts of most of the plots did not contain a determinable amount of phosphorus. Liming increased the phosphate content of the solution from the acid phosphate plots from 0.094 p.p.m. to 0.280 p.p.m. Liming had no influence on the phosphate content of the plots receiving manure or rock phosphate. These results confirm those that have been presented in more detail.

THE CONCENTRATION OF PHOSPHORUS IN THE SOIL SOLUTION AND SOIL EXTRACTS AS RELATED TO PLANT GROWTH

Numerous attempts have been made to secure a laboratory method that will give an accurate measure of the availability to plants of phosphorus in the soil. Some of the methods that have been advanced for the purpose have been partially successful. None of the methods, however, can be considered wholly successful.

A study of the relation between the concentration of the phosphorus in the soil solution and its availability would seem desirable. The results reported in this paper make possible such a study on a limited number of soils whose fertilizer treatment and productive power are known.

The data secured do not indicate a close correlation between the phosphorus content of the soil solution and the availability of the phosphorus in different soils. In fact the data indicate that the phosphorus content of the water extract is in some instances a better criterion of phosphorus availability than the phosphate content of the soil solution. The results secured with the soil from the Toledo field (table 5) serve to illustrate this fact. The plot receiving residues and 8 tons of limestone had almost the same concentrations of phosphorus in the soil solution as the plot receiving acid phosphate in addition to residues and limestone. The plot receiving acid phosphate and residues but no lime had less than one-eighth as much phosphorus in the soil solution as the plot receiving residues and lime. The results are: 0.05 p.p.m. PO_4 for the "residue and acid phosphate" plot; 0.433 p.p.m. PO_4 for the "residue and lime" plot, and; 0.455 for the "residue, acid phosphate, and lime" plot. The results are not in accord with expectations regarding the availability of the phosphorus to crop plants. The corresponding figures for phosphorus in the 1:5 soil extracts are: trace, 0.12 p.p.m. and 0.4 p.p.m. These results are in the order we would expect from our knowledge of the plots. A study of the data from the Cullar's rotation plots, given in table 2, also shows that the water extracts give results that are in better agreement with the known availability of the soil phosphorus than the results obtained from a study of the soil solution. Apparently, under the conditions of this investigation, the phosphorus content of the soil solution indicates the maximum concentration of phosphorus that can be found in the soil under the particular conditions of salt content and reaction—an equilibrium has been established between the soil solution and the solid phase. On the other hand, the concentration of phosphorus in the soil extract seems to be a good index of the ability of a soil to maintain the phosphorus content of the soil solution.

The water extracts from several of the soils studied give results entirely different, however, from those to be expected from our knowledge of the plots. The soil from plot 11 of the 5-year rotation at Wooster, Ohio gave an extract that contained only a trace of phosphate and yet the average corn yield from this plot is 43 bushels. Likewise, the soil from the unfertilized plot of the Aledo, Illinois field gives an extract very low in phosphorus but the plot has an average corn yield of 56.1 bushels. Similar results were secured from the plots of the Berea, Kentucky field. It is evident, therefore, that the phosphorus content neither of the soil solution nor of the soil extracts is a good indicator of the relative availability of phosphorus in different soils. There is, apparently, another factor or group of factors, influencing phosphorus availability that as yet has not been thoroughly studied or measured. The amount and nature of the soil colloids is undoubtedly one important factor to be considered in some detail. Before definite conclusions can be drawn regarding the problem of phosphorus availability it will be necessary to make a more thorough study on a number of soils, including greenhouse studies on the

response of different crops to phosphatic fertilization when grown on different soils.

Another phase of the phosphorus problem of interest in connection with the results obtained is that of the absorption of phosphate by plants from solutions of different concentrations. The concentration of phosphorus in the soil solution is evidently very low, rarely 1.0 p.p.m. PO_4 and frequently as low as, or lower than, 0.1 p.p.m. The concentration of phosphorus in the fertilized plots of the Aledo, Illinois field was approximately 0.1 p.p.m. PO_4. Do plants secure their phosphorus from solutions of such low concentration? Most culture solutions contain over 100 p.p.m. PO_4. Hoagland and Martin (8) have shown that barley will make a good growth in culture solutions containing as low as 1.1 p.p.m. PO_4. When the concentration was reduced to 0.7 p.p.m. the yield of barley was considerably reduced. Their results indicate that growth would be poor in a solution containing only 0.1 p.p.m. PO_4. If this is the case how can one explain phosphate absorption by the plant? Does the plant secure its phosphorus from the same soil solution that is obtained by the displacement method? A study of the application of Donnan equilibria to soils has led the writers to believe that the plant does not necessarily obtain all of its phosphorus from this soil solution. It seems probable that the plant may obtain most of its phosphorus from a solution at the surface of the soil particle and that the phosphate concentration of this solution may be considerably greater than that of the remainder of the soil solution.

According to the Donnan theory of membrane equilibria non-diffusible ions on one side of a membrane cause an unequal distribution of the diffusible ions on the two sides of the semipermeable membrane. Donnan (7), discussing the application of the theory to soils, states that the presence of a membrane is not necessary to the establishment of a Donnan equilibria. Loeb (11, chapter 9) has shown that such an equilibrium is established when particles of gelatin are suspended in solutions. Wilson (4) gives an explanation of the Donnan theory as applied to colloidal particles. He also explains some of the properties of colloidal gold on the basis of the Donnan theory. The authors (17) have suggested the Donnan theory as an explanation of the fact that a soil suspension will invert more sugar than a soil extract of the same hydrogen-ion concentration. The soil particles of an acid soil contain alumino silicates that act as non-diffusible ions. They cause an unequal distribution of the hydrogen-ion at the surface of the particle and in the free soil solution, the H-ion concentration being greatest at the surface of the particle. In a similar manner the soil particles contain compounds of iron, of aluminum, and of calcium that behave as non-diffusible ions. These compounds would, therefore, cause a higher concentration of phosphorus at the surface of the particle than in the soil solution that is obtained by displacement. The plants may, therefore, obtain their phosphorus from this more concentrated solution at the surface of the particle. Using the above explanation as a working hypothesis

the writers are conducting some experiments to determine the validity of the explanation. The data secured will be presented in a subsequent paper.

There is some evidence in the literature indicating that plants obtain their phosphorus from a more concentrated solution at the surface of the soil or phosphate particle. The experiments cited do not offer positive proof of the suggested hypothesis but they are subject to that interpretation.

Kossovitch (10) has shown that plants grow much better in sand cultures in which rock phosphate is mixed with the sand than in similar cultures which derive all their phosphorus from the daily leaching of cultures containing rock phosphate. He attributes the increased growth of plants in the first series to the action of the roots on the particles of phosphate. However, it may be that the concentration of phosphorus at the surface of the phosphate particles was much greater than in the leachings from the culture. Marias (12) has shown that root development of plants in sand cultures containing plates of insoluble phosphate, is limited almost exclusively to the surface of the phosphate plates. Undoubtedly the plants secured practically all of their phosphate from the surface of these phosphate plates. The experiment indicates that the contact of the roots with the particles of insoluble phosphate is essential to growth. This may be due to the fact that the roots have a corrosive or solvent action on the phosphate or to the fact that the phosphate concentration at the surface of the particle is higher than in the remainder of the culture solution. Therefore, the plants would secure their phosphorus from the more concentrated solution. The concentration of phosphorus in the remainder of the solution was probably too low to permit absorption by the plant.

SUMMARY

The experiments reported were undertaken to determine the influence of lime and of different phosphatic fertilizers on the concentration of phosphorus in the soil solution and in soil extracts. The study was made on soils from field experiments in Alabama, Illinois, Ohio, and Kentucky. The phosphatic fertilizers used in the experiments included acid phosphate, rock phosphate, steamed bone meal, and basic slag.

The soil solution was obtained by the displacement method. Soil extracts were prepared by use of collodian sacks, the diffusate being used for the determination of phosphorus. The latter was determined by a rapid, sensitive colorimetric method.

Liming increased the phosphorus content of the soil solution and of the extracts from soils receiving acid phosphate or basic slag. The influence of lime on the solubility of rock phosphate was not great; in some cases it apparently increased, and in others reduced, the availability of rock phosphate. Liming had a very decided, depressing effect on the solubility of phosphorus in steamed bone meal.

The results of an experiment show that the soil has a remarkable capacity for maintaining a given concentration of phosphorus in the soil extract.

The relation of the results to the absorption of phosphorus by plants is discussed. It seems doubtful whether plants absorb all of their phosphorus from solutions of as low a concentration as the soil solution. In the soils studied, the soil solution rarely contained 1.0 p.p.m. PO_4; frequently it was less than 0.1 p.p.m. Reasoning from the basis of an application of the Donnan theory of membrane equilibria the authors advance the hypothesis that the concentration of phosphorus at the surface of the soil particle is greater than in the soil solution obtained by displacement. A plant probably absorbs some of its phosphorus from this more concentrated solution at the surface of the soil particle.

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SYNTHETIC CALCIUM SILICATES AS A SOURCE OF AGRICULTURAL LIME: II. A COMPARISON OF THEIR INFLUENCE WITH THAT OF OTHER FORMS OF LIME UPON CERTAIN MICROBIOLOGICAL ACTIVITIES IN THE SOIL[1]

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A comparative study of the influence of several different forms of lime on plant growth was reported elsewhere (1). Certain bacteriological studies were made parallel with those vegetation studies, with particular reference to the influence of synthetic calcium silicates as carriers of agricultural lime. The microbiological factors investigated in this connection were: (*a*) bacterial numbers, (*b*) nitrate formation and (*c*) sulfate formation. The numbers of microorganisms and the nitrate formation in the soil were selected because, as Waksman has shown elsewhere (25, 26), the results obtained from a study of these factors can serve as functions of the microbiological condition of the soil. The results are briefly reported here.

INFLUENCE OF VARIOUS FORMS OF LIME UPON BACTERIAL NUMBERS IN THE SOIL, AS DETERMINED BY THE PLATE METHOD

Déhérain (7) reported interesting data on the increase in numbers of bacteria with increased applications of calcium carbonate. Fischer (9) found that both calcium oxide and calcium carbonate produced an increase in the number of bacteria in the soil, especially where small amounts were used (e.g., 0.1 per cent CaO). With the addition of lime the bacteria increased in greater proportion than the molds. Engberding (8), Brown (3), and Bear (2), working usually with one form of lime, have observed an increase in bacterial numbers with applications of lime. Hutchinson (12) observed that whereas small amounts of CaO increased the bacterial numbers, large applications decreased the numbers. Connor and Noyes (6) observed that on some soils magnesite encouraged the multiplication of both aerobic and anaerobic bacteria more than did calcite, whereas on other soils the reverse was true. As shown elsewhere (25) the

[1] Part II of a dissertation presented to Rutgers University in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

[2] The author takes this opportunity to express his appreciation of the sincere interest manifested by Dr. Selman A. Waksman in the direction of this problem.

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continued application of lime to a Sassafras soil resulted in a decrease in the number of fungi and an increase in the number of bacteria and especially of actinomyces.

In these experiments, a study was made on the influence of ground limestone, of calcium hydrate, and of di-calcium silicate on the bacterial numbers of a Sassafras loam removed from experimental plots N and 11A of the station. The soil from plot N has received annual applications of muriate of potash and acid phosphate for over ten years. The soil from plot 11A has received annual applications of potash, acid phosphate, and nitrogen in the form of

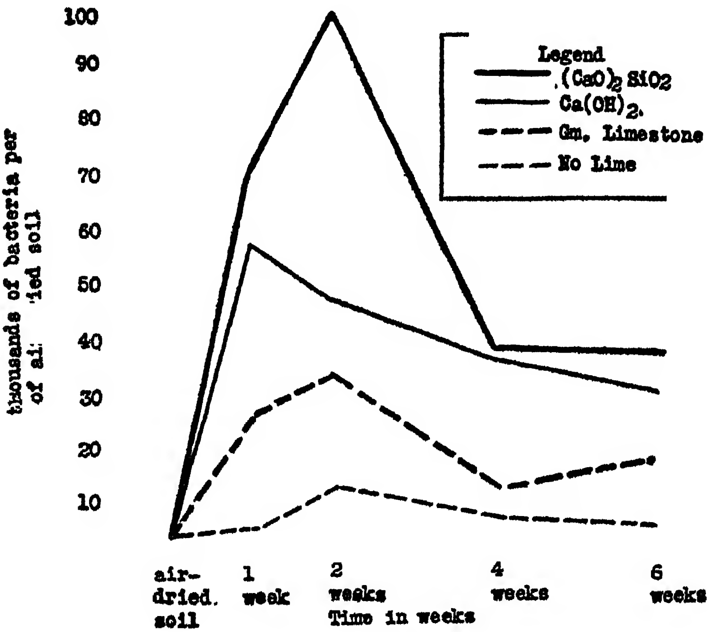

FIG. 1. SHOWING THE VARIATIONS IN THE NUMBERS OF BACTERIA IN SOIL FROM PLOT N TREATED WITH DI-CALCIUM SILICATE, CALCIUM HYDRATE, AND GROUND LIMESTONE ON AN EQUIVALENT LIME BASIS AT VARIOUS INTERVALS AFTER TREATMENT

ammonium sulfate for over ten years time, but no lime, and was therefore very acid (pH = 4.05).

Quantities of these two soils were weighed into pots and treated with calcium hydrate, ground limestone, and di-calcium silicate on an equivalent CaO basis. A constant moisture content was maintained and samples were taken at intervals for the determination of the bacterial numbers, sodium albuminate agar (10) being used. Two plates of two dilutions were made and incubated at 28°C. Counts were made after 24- and 48-hour incubations.

The treatments used and the numbers of bacteria expressed as hundred thousands per gram of air-dried soil are given in table 1. In both soils the

bacterial numbers increased to a maximum within one or two weeks and decreased to almost a constant number within the following few weeks. It is significant that the influence of air-drying followed by moistening should produce this result not only in all of the variously limed soils but also in the untreated soils, this effect corresponding to partial sterilization [Waksman and Starkey, (27)]. Similar results were obtained by Rahn (23) and Heinze (11).

The bacterial numbers of the soil from plot N were, on an average, influenced by the application of di-calcium silicate, of calcium hydrate, and of ground

TABLE 1

Bacterial numbers in soils from plot N and plot 11 A treated with various forms of lime on an equivalent lime (CaO) basis*

TREATMENT	EQUIVALENT APPLICATION OF CaO PER ACRE	AIR DRIED SOIL	AFTER 1 WEEK	AFTER 2 WEEKS	AFTER 4 WEEKS	AFTER 5 WEEKS	AVERAGE
	pounds						
Soil from plot N†							
No lime	2,000	4.50	5.87	13.90	8.70	5.95	8.61
16.30 gm. ground limestone	2,000		26.00	34.40	13.40	22.80	21.25
19.20 gm. di-calcium silicate	2,000		70.00	100.00	38.80	37.60	61.60
11.70 gm. calcium hydrate 4.27 gm. hydrated silica	2,000		57.00	46.60	36.20	30.00	42.70
Soil from plot 11 A‡							
No lime	2,000	3.60	15.94	10.50	8.60	4.94	7.49
9.06 gm. ground limestone	2,000		26.00	68.00	38.30	32.40	41.17
10.66 gm. di-calcium silicate	2,000		55.00	55.60	61.00	48.20	54.95
6.50 gm. calcium hydrate	2,000		32.00	28.00	30.00	32.80	30.70

* Expressed in hundred thousands per gram of air-dried soil.
† 18 pounds of soil per pot.
‡ 10 pounds of soil per pot.

limestone in order. (Fig. 1.) If the differences in the average relative crop yields as reported in a previous publication (1) are taken as significant, a very interesting correlation is found between crop yields and the stimulating effect of different forms of lime upon bacterial numbers. The same general trend is observed with the soil from plot 11A, though the correlation is not so perfect.

INFLUENCE OF VARIOUS FORMS OF LIME UPON NITRATE FORMATION IN SOIL

The favorable influence of lime generally observed, both in the field and in laboratory studies, upon nitrate formation in the soil has been found to be due

TABLE 2

Nitrification of ammonium sulfate in soil treated with increasing amounts of Limosil and with several forms of lime as an equivalent CaO basis

TREATMENT	EQUIVALENT APPLICATION OF CaO PER ACRE	SOIL FROM 11A			SASSAFRAS LOAM			PENN LOAM		
		pH of soils at beginning of nitrification	Increase in N as NO_3 for each 100 gm. soil*	N added as $(NH_4)_2SO_4$ nitrified	pH of soils at beginning of nitrification	Increase in N as NO_3 for each 100 gm. soil*	N added as $(NH_4)_2SO_4$ nitrified	pH of soils at beginning of nitrification	Increase in N as NO_3 for each 100 gm. soil*	N added as $(NH_4)_2SO_4$ nitrified
	pounds		*mgm.*	*per cent*		*mgm.*	*per cent*		*mgm.*	*per cent*
Nothing	.....	4.05	−1.00		5.45	0.254	0.479	6.4	11.153	21.04
Limosil	500	5.30	0.149	0.281	5.50	0.578	1.090	6.7	14.430	27.22
Limosil	1,000	5.30	1.248	2.354	5.80	1.526	2.880	6 8	12.938	24.40
Limosil	2,000	5.85	3.899	7.356	6.05	5.928	11.190	6.9	21.117	39.80
Limosil	4,000	6.40	10.814	20.403	6.50	12.017	22.720	7.2	37.987	71.55
Limosil	2,000	5.85	3.899	7.356	6.05	5.928	11.190	6.9	21.117	39.80
Ground limestone	2,000	5.90	4.841	9.134	6.10	7.072	13.350	6.7	18 404	34.37
Calcium hydrate	2,000	5.90	3.451	6.511	5.90	5.239	9.880	6.8	21.390	40.30
Di-calcium silicate	2,000	5.90	2.640	4.981	5.90	9.315	17.580	6.9	15.634	29.52

* Air-dried basis.

largely to the neutralization of the acids formed in this process, thus creating a more favorable medium for the activities of the bacteria concerned. As a matter of fact, it has even been found (26) that in the case of an acid soil there is a direct relation between the amount of nitrate formed from ammonium salts and the buffering power (or presence of available base) of the soil. The erroneous idea of some early workers that nitrates are not formed in acid soils has been disproved by numerous investigators, however an adequate supply of basic materials was found to increase the speed of nitrate formation. In the numerous investigations reported, various forms of lime have been used with practically similar results: an increase in nitrification due to liming [Noyes and Connor (21) and Waksman 26)].

Soils previously treated with various liming materials and cropped several times (1),[4] were used in further experiments on the effect of increasing amounts of limosil on the nitrification of ammonium sulfate, and for a comparison of the effects of various liming materials furnishing the same amount of CaO. Soils

TABLE 3

Relation between increase in nitrate nitrogen (per 100 gm. of air-dried soil) and increased yield of crops on two soils treated with increasing amounts of limosil

LIMOSIL TREATMENT*	EQUIVALENT APPLICATION OF CaO PER ACRE	SOIL FROM PLOT 11A		SASSAFRAS LOAM	
		Increase in weight of crop over no lime pot	Increase in nitrate N over no lime†	Increase in weight of crop over no lime pot	Increase in nitrate N over no lime
gm.	*pounds*	*gm.*	*mgm.*	*gm.*	*mgm.*
2.769	500	12.6610	0.149	5.4599	0.324
5.538	1,000	14.8367	1.248	6.8327	1.272
11.076	2,000	20.8974	3.899	8.3571	5.674
22.152	4,000	24.9890	10.814	13.5445	11.763

* 10 pounds of soil per pot.

† Based on laboratory studies.

from the acid plot 11A of the New Jersey plots, from an old unlimed grass land (Sassafras loam), and from a well-limed alfalfa field (Penn loam) were used in these experiments. Short descriptions of these soils were given elsewhere (1). After the removal of the last crop, the three soils used under various lime treatments in pot culture work were thoroughly air-dried and used for the study of nitrate formation. Fifty-three milligrams of nitrogen in the form of ammonium sulfate was added to 100 gm. of soil placed in tumblers, and each soil was brought to its optimum moisture content.

At the end of an incubation period of 28 days a 1 to 5 water extract of the soil was made and the nitrates were determined by the phenoldisulfonic acid method. Alum was used as a clarifier when necessary. Excellent agreement was obtained in the tumblers of like treatment. Table 2 gives the treat-

[4] Limosil is an impure product—possibly a mono-calcium silicate is present as well as about 13 per cent free lime. The product contains about 41 per cent total CaO.

ments, the increase in nitrate nitrogen content, and the percentage nitrification of the nitrogen added as ammonium sulfate.

Increased nitrification of ammonium sulfate followed with the increased application of limosil, the single exception being the 1000-pound application on the Penn loam. As would be expected, the several forms of lime were individual in their effects on nitrification in the various soils. For this reason there can be no correlation between nitrification as studied under laboratory conditions and the several crop yields. However, as shown in table 3, there is a correlation between the gain in nitrates produced by a given material (i.e. limosil) and the increase in crop production. Figure 2 shows the correlation between increase in nitrate production and increase in crop yield as obtained with the soil from plot 11A.

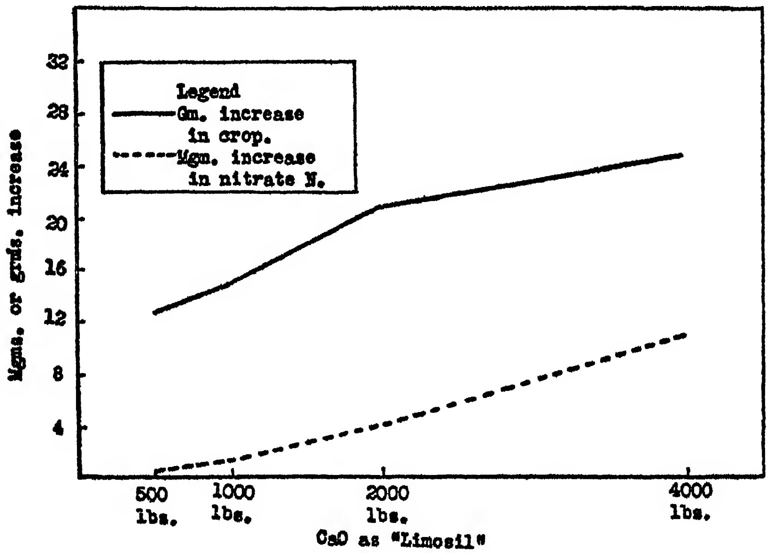

FIG. 2. SHOWING CORRELATION BETWEEN INCREASE IN CROP PRODUCTION AND INCREASE IN NITRATE NITROGEN (PER 100 GM. OF AIR-DRIED SOIL) IN SOIL FROM PLOT IIA TREATED WITH INCREASING APPLICATIONS OF LIME AS LIMOSIL

Though the rate of nitrification may vary with the form of lime used, yet a final and maximum production of nitrates (for a given set of conditions) in soils treated with the different forms of lime on an equivalent lime basis must be the same, at least under conditions precluding leaching of the soil. Thus when two soils were treated with various forms of lime and left standing under favorable conditions of temperature and moisture for a period of 30 weeks, the results as indicated in table 4 were obtained. No nitrogen-carrying compounds were added.

In the Elkton silt loam and in the Sassafras loam, the final accumulation of nitrates was the same, regardless of the form of lime applied, where the same

amount of lime (CaO) was furnished in the various forms. From the meager data at hand it is impossible to say which form of lime causes nitrification to proceed at the greatest rate. It seems plausible, however, that those forms which are the more soluble and hence more active chemically, e.g., the oxide and hydrate, would bring about a very favorable condition for nitrification immediately after application, if not applied in amounts which inhibit bacteriological processes, as shown by Fischer (9) Hutchinson (12), Hutchinson and MacLennan (13), Miller (20), Waksman and Starkey (27) and others.

THE INFLUENCE OF VARIOUS FORMS OF LIME UPON SULFATE FORMATION IN THE SOIL

The most extensive works on the effect of lime on the removal of sulfur from the soil are the lysimeter experiments of Lyon and Bizzell (16, 17) and MacIntire and associates (18). The study of the leachings from limed and unlimed soil indicates that applications of lime tend to increase the removal of sulfates from the soil. Lyon (15) in a review of many experiments makes the statement:

TABLE 4

Influence of several forms of lime applied on an equivalent lime basis on the nitrification of soil nitrogen

TREATMENT	ELKTON SILT LOAM*		SASSAFRAS LOAM†	
	N as NO_3 per 100 gm. soil	Relative nitrate content	N as NO_3 per 100 gm. soil	Relative nitrate content
	mgm.		*mgm.*	
No lime	3.09	100	3.94	100
Calcium oxide	7.69	249	5.88	149
Calcium hydrate	7.70	249	6.63	168
Ground limestone	7.69	249	7.00	177
Di-calcium silicate	7.70	249	6.25	158
Limosil	7.33	237	5.75	145
Calcium oxide equivalent to free CaO in limosil	4.35	141	3.50	89

* Liming materials added to furnish 3200 pounds CaO per acre.

† Liming materials added to furnish 2000 pounds CaO per acre.

> The effect of liming on the removal of sulfur in the drainage water is difficult to understand. Apparently when conditions are made more favorable for nitrification they are not always more favorable for sulfofication. In other words, when liming increases nitrification it may or may not promote sulfofication. The data do not permit any further generalization. There is some indication, however, that a subsoil may absorb much of the sulfate formed in the upper soil.

The results obtained by other investigators, such as Plummer (22), Christie and Martin (5), Lipman and Gericke (14), Robinson and Bullis (24), and others, do not improve upon the generalizations of Lyon. Brown and Kellogg's

(4) investigations on the best method for the determination of sulfates in soils revealed some very interesting information relative to the solubility of soil sulfates in distilled water and in HCl. Their results indicate that extraction with distilled water is to be preferred to extraction with dilute HCl. More recently MacIntire and Shaw (19) have added further information to the subject by their excellent studies relative to the formation of double sulfates of calcium and aluminium or iron in the presence of an excess of calcium hydroxide.

In general it may be expected that the application of lime in the several forms to acid soils will increase sulfate and nitrate formation in the same manner. But definite prediction of the effect of lime on a given soil may not be made without knowledge relative to the forms of sulfur in the soil and to the microbiological processes. The present work gives the results of a study of

TABLE 5

The influence of increasing amounts of lime as limosil and equivalent applications in the several other forms on the readily soluble sulfates of two so-called acid soils and on a limed Penn loam

TREATMENT	EQUIVALENT APPLICATION OF CaO PER ACRE	SO_4 PER 100 GM. SOILS		
		Soil from plot 11A	Sassafras loam	Penn loam
	pounds	*mgm.*	*mgm.*	*mgm.*
No lime		19.89	11.75	22.53
Limosil	500	26.07	12.75	23.14
Limosil	1,000	29.15	13.99	24.57
Limosil	2,000	34.29	18.01	24.57
Limosil	4,000	38.49	24.99	24.78
Limosil	2,000	34.29	18.01	24.57
Ground limestone	2,000	29.34	19.99	22.16
Calcium hydrate	2,000	30.39	17.83	26.86
Dicalcium silicate	2,000	34.18	20.16	22.53

the influence of several forms of lime on the accumulation of water-soluble sulfates in the soil under conditions precluding leaching.

The water-soluble sulfates of the soil from plot 11A, from the Sassafras loam, and from the limed Penn loam used in the other bacteriological studies were determined after the soil was cropped three times and thoroughly screened on removal from the pots. This was accomplished by shaking 200 gm. of soil with 500 cc. of distilled water for 4 hours, filtering the suspension first through a good quantitative filter and then through a Berkefeld filter. The sulfates were determined in the clear filtrate by precipitation with barium chloride. The results, expressed as milligrams of sulfate for 100 gm. of soil, are given in table 5. The amounts of sulfates adsorbed by the plants are not taken into consideration, but they cannot have been very great for the three crops removed. With increasing applications of limosil there is an increase in the sulfates of the soil from 11A and of the Sassafras loam. This increase is not ob-

served with the limed Penn loam. Thus the sulfate formation evidently may be correlated with increased nitrate formation in the former soils, but not in the latter. However, in this connection, it must not be forgotten that the nitrification studies were made in the laboratory and with the addition of nitrogenous materials, whereas the sulfates were formed from the native soil materials. The comparatively low yields of crops obtained on the Penn loam soil probably justify the assumption that both the nitrogen- and sulfur-bearing materials had been more completely decomposed in this well-limed soil, and that hence with further additions of lime there was little or no further decomposition.

A comparison of the results obtained with equivalent applications of limosil, of ground limestone, of calcium hydrate, and of di-calcium silicate, shows that these materials are similar in their influence on sulfate formation, and that equivalent applications give for all purposes the same amount of sulfate. Naturally, the rate of sulfate formation may vary for the several materials.

SUMMARY

A study of the influence of several forms of lime, particularly calcium silicates, on the bacterial numbers, on nitrate formation, and on sulfate accumulation in several soils gave rise to the following generalizations:

1. Chemically equivalent additions of ground limestone, of di-calcium silicate, and of calcium hydrate to soils deficient in basic materials increased the bacterial numbers in these soils in amounts varying with the form and the soil.

2. Following the addition of ground limestone, of di-calcium silicate, and of calcium hydrate a rapid increase in the number of bacteria, followed by a decrease to almost a constant number was observed. This is no doubt due to the increase in available energy as a result of neutralizing the acid reacting organic soil substances; after the energy made more readily available is used, the numbers of bacteria drop.

3. Some correlation was obtained between the fertility of the soils under the various lime treatments and the number of bacteria, as estimated by plating on sodium-albuminate agar.

4. With increasing applications of lime as limosil there is a corresponding increase in the formation of nitrates from ammonium sulfate. This increase can be correlated with increased yield of crop.

5. Though chemically equivalent amounts of ground limestone, calcium hydrate, di-calcium silicate, and limosil influenced differently the rate of nitrate formation, the final accumulations of unleached nitrate were the same, regardless of the form of lime.

6. Extracts of two acid soils and of one well-limed soil were made and analyzed for sulfates. The soils had been treated with increasing applications of limosil and with chemically equivalent applications of calcium carbonate, calcium hydrate, limosil and di-calcium silicate, held under conditions precluding leaching, and had been cropped three times. The two acid soils showed an increased sulfate formation with an increased application of limosil, but the well-limed soil showed very small increases of sulfate with an increased limosil application. Chemically equivalent applications of the four substances affected the sulfate formation in the same manner in the three soils, producing substantially the same amount of sulfates. This is no doubt due to the increased microbiological activities, which resulted in a greater decomposition of organic matter and, therefore, in a greater liberation of sulfur in the form of soluble sulfates.

7. The rapidity of the changes in the microbiological processes of the soil differed with

the nature of the material, though the final effects of chemically equivalent quantities of the several liming materials were the same. This may serve to explain the difference in the yields of the individual crops as a result of the different liming materials, although the averages of the results give practically no differences.

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CONTRIBUTION TO THE THEORY OF THE ORIGIN OF ALKALI SOILS

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An understanding of the characteristic properties of a soil, necessitates a study of its origin. Since the publication of the author's monograph on the alkali soils in Hungary, some of the publications of W. P. Kelley, C. S. Scofield, J. S. Joffe and H. C. McLean, and especially the English translation of the papers of the Russian investigator, K. K. Gedroiz,[1] have appeared. These confirm the author's experiences, some of which might supplement the results of the others. Most of the author's investigations were published in Hungarian, during and after the war, and no opportunity presented itself to translate them into English or other international language. As the author has now been charged by C. F. Marbut, chairman of the Fifth International Soil Commission, to organize an international subcommittee for the study of alkali soils, he feels it necessary to make available for further discussion his own experiences. The author does not intend to discuss in this paper the whole material treated by the above quoted investigators and by himself, but to recapitulate the different theories on the origin of alkali soils.

The first scientifically supported theory on the origin of alkali soils was presented by E. W. Hilgard, who pointed out the difference between the littoral and the terrestrial salty soils. The latter were called alkali soils and were designated as a product of climate. According to this theory, they are the result of rainfall insufficient to leach out the salts that are formed progressively by the weathering of soils minerals; therefore, the more arid the climate, the more chance there is for the accumulation of alkali in the soil. Hilgard treated the alkali soils as more or less impregnated with different sodium salts and emphasized largely the obnoxious effects of the latter on crops and fruit trees. In all his publications on this subject, he stressed the fact that if the obnoxious salts are leached out, a soil of good fertility and of normal physical properties is formed. According to this theory, the problem of alkali-reclamation consisted chiefly in washing out these harmful soil constituents by irrigation and drainage.

The author is far from minimizing the high merits of the old master on alkali

[1] Translated by S. A. Waksman of the New Jersey Experiment Station, New Brunswick, N. J., and mimeographed under the supervision of C. S. Scofield, U. S. Department of Agriculture, Washington, D. C.

reclamation. His pioneer work represents fundamental experiences in the utilization of alkali lands, and was the real starting point in the systematic reclamation all over the world. When, however, the author began in 1900 to study the Hungarian alkali soils, called "Szik"- or "Szék"-lands, he was immediately struck by two difficulties that could not be explained by the above-mentioned alkali theory. In the first place: Why are alkali soils scattered right amidst the best wheat soils? There is no appreciable difference in the climatic conditions and very often none in the topographic conditions which could throw light on the origin of alkali accumulation; for example, very frequently the worst alkali spots are found on the more level parts of the land. The second evidence against the alkali theory of Hilgard consisted in the fact that a considerable part of the alkali soils in Hungary, though practically deficient in sodium carbonate, and very poor indeed in water-soluble salts—ranging no higher than 0.15 to 0.20 per cent in the soil—proved *practically impermeable* to water and air, and showed the same physical properties as the real black alkali soils described by Hilgard. When moistened, the soil becomes fluid and fills up the cracks and fissures of the underlying soil layers, which were previously dry; hence, the checkered appearance of the upper horizons, frequently observed in this class of alkali soils. This liquefying property of the surface horizon is very characteristic of this type of alkali soil and, as will be seen later, bears the proper relation to the composition of the so-called zeolite-humus-complex of the soil, regardless of the temporary salt content or occurrence of black alkali in the soil. It sounds paradoxical that the wetting or the penetration of the water in this liquescent matter is extremely slow and does not reach any considerable depth. Hilgard ascribes the impermeability and puddling of the alkali soil to the carbonate of soda. In this case no carbonates whatever are found in the soil, but we have to do here with a zeolite-humus-complex saturated more or less with sodium ions, or with amorphous sodium zeolites and humates in a colloidal dispersion. When dry, the soil becomes hard like stone and quite untillable. In the second soil horizon, nearer to the surface, is found the impervious hardpan, called "Szikfok," impregnated with dark colored humus and colloidal zeolites. This horizon has a more or less developed structure, resembling the profile of the Russian "Solonetz." Here again very often the salt content is quite inconsiderable and the carbonate of soda quite absent, showing that contrary to Hilgard's belief, *the occurrence of this type of hardpan is independent of the presence of sodium carbonate.*

The first adverse criticism of Hilgard's theory was soon eliminated by the study of the mechanical and physical condition of the alkali soil profiles, showing that *in every case of alkali accumulation*, even in the sandy alkali soils, *an impervious subsoil* is found. Moreover, at certain times a close relation is found between the depth of the impervious soil-layer and the accumulation of the salts, the latter being the more accentuated, the nearer it is to the impervious subsoil. This might be illustrated by the profile of the soil-section of an

irrigated alkali land at Békéscsaba surveyed by the author as far back as 1903 (12, 14). It may be of some interest to see how the fluctuation of the salt content and the depth of the impervious subsoil interfere; therefore since the authors original publications in Hungarian would hardly be available to American investigators and since the Proceedings of the First Agrogeological Conference, in which the author's results have been briefly reported in German, are already unavailable they are briefly summarized here. The distribution of the total salts to an average depth of 120 cm. is reproduced on the soil map

TABLE 1

Mechanical analysis of Békéscsaba and Cservenák soils

DIAMETER OF SOIL FRACTIONS	ALKALI SOIL AT BÉKÉSCSABA PLOT 38			WHEAT SOIL OF CSERVENÁK	
	Depth of the soil layer				
	0 to 30 cm.	60 to 90 cm.	190 to 220 cm.	0 to 30 cm.	230 to 270 cm.
mm.	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
1–0.5	.....	.....	.....	1.86	21.41
0.5 –0.2	0.44	.....	0.42	23.32	11 99
0.2 –0.1	7.37	6.99	2.11	25.10	26.55
0.1 –0.05	22.56	16.85	5.46	17.10	10.49
0.05–0.02	10.63	16.45	13.02	5.88	8.14
0.02–0.01	6.07	2.68	4.62	2.41	4.71
0.01–0.0025	26.03	31.25	34.88	19.31	10.71
0.0025	26.90	25.78	39.49	5.02	6.00
Total.......	100.00	100.00	100.00	100.00	100.00

TABLE 2

Permeability of water in Békéscsaba and Cservenák soil-profits

Time when water disappeared..............	Not reached	Not reached	Not reached	5 hr. 20 min.
Depth to which the soil column became moist when water disappeared......*mm.*	0	0	0	320
Final depth of the moistened soil column..........................*mm.*	55	48	22	565
Water column above the soil, at the end of the experiment...................*mm.*	89	80	85	Nothing
Experimental period................*days*	16	6	6	16

(plate 1), covering an alkali land of about 102 hectares. Samples were taken from two or more depths in about fifty different places, and the average salt content was used for the classification. The limits of the salt classes were mapped according to the natural or planted vegetation, because a close connection has been found to exist between the salt content of the soil and the vegetation supported by it. Consequently the salt classification is in full harmony with the cultural classification. The author does not intend to treat here in greater detail the methods of surveying, though they are in some

respects different from those used in America. He intends to show only how the vertical distribution of the four typical soil-horizons fluctuates in a cross-section through the different salt classes, along the ABCEDFGH-line on plate 1. This and the corresponding average salt-content are reproduced on plate 2. The uppermost horizon represents the limit of the more or less dark-colored humus-horizon, which is itself divided into at least two different horizons, i.e., the surface eluvial, and the subsurface accumulation horizon. The second horizon (plate 2) consists of a yellow marl with numerous concretions of calcium carbonate. Then follows, in different thicknesses, a sandy loam, rich in micas, and under this the impervious bluish clay, recovered in every alkali formation of similar type. If the corresponding salt-content in plate 2, figure 2 is now compared with the fluctuation of this impervious clay-horizon, it becomes evident that the nearer the latter approaches the surface, the more the salts accumulate.

Close to this alkali land, the best wheat-soils, with no trace of alkali, are found. It was interesting to investigate whether this impervious clay can be recovered here and to what depth. The soil examined was on the Cservenák farm, where, although the climatic conditions hardly differed from those of Békéscsaba, there was no trace of alkali in the soil. But, on the other hand, there was a striking difference in the mechanical composition, as well as in the physical properties of both soils. In table 1, the respective analyses of a heavy alkali soil-profile at Békéscsaba and on the farm of Cservenák are given.

The results of some experiments on the permeability of both soil-types are reported in table 2.

The data in both tables prove definitely that here we have to do with two soils of quite different physical properties, and especially that, in the case of the wheat soil of Cservenák, the drainage of the whole soil-profile is a good one whereas that of Békéscsaba is quite deficient. It seems very likely that the alkali salts in the case of the good soil were drained to the deeper soil-layers, and in fact, if a bore is made to a depth of 10 to 15 m., saline water is found similar in composition to the subsoil water of the alkali soil at Békéscsaba at a depth of about 2 or 3 m. Tables 3 gives the chemical composition of both waters.

It follows then that, under the climatic conditions prevailing in Hungary, the natural leaching of the alkali salts is possible when there is not an impervious subsoil, which prevents the natural drainage and causes the accumulation of the water-soluble salts in the upper layer.

The same was found in the sandy alkali soils. In this case a calcareous hardpan is found at a depth of about 1 to 3 m. under the sandy layer, again preventing any drainage. This hardpan is made up of the same sand with calcium carbonate. For the formation of this hardpan the black alkali present in these soils again might not be responsible, but there is every evidence of former swampy formations. On the other hand, the same calcareous hardpan is found in the more level parts of the adjoining soils where alkali does not

occur, showing that, in early times, when the stagnant water-level was higher than now, the swamp formation of this area was considerably greater. This is in full harmony with the historical fact, that, before the regulation of the streams, and the protecting of the lowland against the yearly inundations, the swampy and peaty areas were very considerable. Now in the lowest basins of this territory the typical black alkali soils are found.

Here the *third factor in the genesis* of the alkali soils is found; namely, under the semiarid climatic conditions found in Hungary the alkali occurrence coin-

TABLE 3

Chemical composition of subsoil water of Békéscsaba and Cservenák soils

	WATER, 210–240 CM. DEEP AT THE ALKALI FIELD NO. 12 AT BÉKÉSCSABA	DEEP-WELL-WATER IN THE CSERVENÁK FARM. DEPTH OF THE SPRING ABOUT 10–15 M.
	p.p m.	*p p m*
Na	2048.32	528 90
K	44 00	70 32
Ca	76.76	92 54
Mg	295 99	119 75
Cl	2214 00	105 10
SO_4	2474.82	908 29
NO_3	...	45 52
$\frac{1}{2}CO_3$	.....	63.78
HCO_3	252 16	881.70
CO_2 (free)	547 30	Not determined
Total	7953.35	2815 93

Percentage composition of positive and negative ions in gram equivalents

		per cent	*per cent*
Positive ions	Na	75.3	58.5
	K	0.9	4 6
	$\frac{1}{2}Ca$	3.2	11.8
	$\frac{1}{2}Mg$	20.6	25 1 (Na–Mg: 100)
Negative ions	Cl	52 9	7 6
	$\frac{1}{2}SO_4$	43.6	48 2
	NO_3	.....	1 9
	$\frac{1}{2}CO_3$	3.5	5 4
	HCO_3	......	36 9 (Cl–HCO_3: 100)
Free CO_2		9.9	Not determined

cides with that territory which was *temporarily overflowed with shallow water*. The intensive evaporation of water in the dry summer and the imperviousness of the subsoil which prevented any drainage, caused the water-soluble salts to accumulate more or less according to the local soil and hydrological conditions. The author does not assume that in the drier countries, like the deserts of Africa, of Asia and of America, where the evaporation factor may be more

effective, the accumulation of alkali may be a purely climatic effect, though even in that case the temporary abundance of soil-humidity seems to be necessary to dissolve the salts and to bring them by capillarity or seepage to the surface soil. The writer does not feel authorized to decide this question, but the occurrence of the alkali soils which were visited in the United States and in Egypt, as well as the publications of the respective countries affirm this supposition and agree with the theory of the Russian agrogeologist K. Glinka (4). In his book on the different types of soil-formation, Glinka treats the continental salty soils in a separate chapter, characterizing them as *products of temporary over-abundance of humidity*, pointing out that, under similar conditions in the humid climate, there would result real peats and swamps. But there is a striking difference in the soil-forming factors of the two related types. In the case of swamps, the soil is formed in a somewhat acid medium, in contrast to the reaction of alkali soils. By this he does not mean the true alkaline reaction of normal sodium carbonate, but includes all carbonates soluble in the soil moisture.

The author does not intend to treat in detail Glinka's classification of the different salines, which harmonizes in many respects with his own published in German some years before (16), but the discussion will be confined to the theory of soil-formation in alkaline medium suggested first by Glinka. He shows by different water extracts, that the soil solution of the solonetz type of soil is always alkaline, as the water extracts contain not only bicarbonates, but also normal carbonates which can be titrated with phenolphthalein. He further states, that the quantity of humus increases with the alkalinity of the soil-horizon. He suggests also that to dissolve humin substances the presence of normal carbonate of soda is required. An experiment is described which consists of treating a salt-free tschernozem with a solution of bicarbonate of soda or with the normal sodium carbonate, with the result that, in the first case, the percolation of the solution was very quick, and the percolate was faintly colored; in the case of the normal carbonate, the humus of the soil gave a dark solution, forming at a certain depth a dark-colored ring and preventing any further water movement. Similar phenomena have been observed repeatedly in the author's earlier experiments (12, 14). Nevertheless, to see how these phenomena change with the concentration and the mixing-ratio of the different sodium salts, the following experiments were undertaken with the assistance of Emil Bräutigam.

An alkali-free garden soil, rich in humus and in calcium carbonate was treated with different quantities of sodium salt solutions. The data are reported in table 4. To test the dissolved organic matter, different methods of determinations were used. As seen in table 4 the quantity of 0.1 N $KMnO_4$, necessary for oxidizing the dissolved total organic matter was determined. For this purpose a surplus of the permanganate solution was added to 10 or 20 cc. of the soil solution, at ordinary laboratory temperature; then after boiling, 100 cc. of 2 N sulfuric acid and 10 cc. of 0.1 N oxalic acid were added.

The latter formed an excess and the resulting solution became colorless; the surplus oxalic acid was then titrated back with the permanganate solution. The amount of permanganate necessary for the oxidizing of the organic matter could thus be determined. The corresponding amounts of oxygen and of

TABLE 4

Influence of salt solutions upon the extraction of organic matter from an alkali-free soil

NUMBER OF EXPERIMENT	QUANTITY OF SOIL USED	AMOUNT AND NATURE OF THE SOLUTION USED	IN 100 CC. OF SOLUTION					COLORIMETRIC VALUES ACCORDING TO LOVIBOND
			Time of revolving	Volume of the solution used for the determination	0.1 N permanganate used for oxidation	Corresponding amount of oxygen	Corresponding organic matter	
	gm.		*hrs.*	*cc.*	*cc.*	*mgm.*	*mgm.*	
1	50	500 cc. N Na_2CO_3	24	10	18.58	14.98	44.41	95.5
2	50	500 cc. N Na_2CO_3	48	10	18.58	14.88	44.41	98.0
3	50	500 cc. N Na_2CO_3	120	10	18.58	14.88	44.41	98.0
4	5	500 cc. N Na_2CO_3	24	10	3.54	2.80	8.46	9 0
5	50	500 cc. 0.1 N Na_2CO_3	24	10	17.70	14.16	42.30	Over 100.5
6	5	500 cc. 0.1 N Na_2CO_3	24	10	2.65	2.16	6.33	28.5
7	50	500 cc N Na_2SO_4	24	10	2.21	1.76	5.28	6.0
8	50	500 cc. N NaCl	24	20	0.88	0.72	2.10	2.5
9	50	500 cc. N $NaHCO_3$	24	10	7.69	6.40	19.02	38.0
10	50	{250 cc. N Na_2CO_3, 250 cc. N NaCl}	24	10	12.39	9.92	29.61	67.0
11	50	500 cc. 0.1 N $NaHCO_3$	24	10	0.88	0.72	2.10	1.0
12	50	{50 cc. N Na_2CO_3, 450 cc. N NaCl}	24	10	7.04	0.56	16.83	24.0
13	50	{50 cc. N Na_2CO_3, 450 cc. N Na_2SO_4}	24	10	11.10	8.88	26.53	56.0
14	50	{250 cc. 0.1 N Na_2CO_3, 250 cc. 0.1 N NaCl}	24	10	9.77	7.84	23.35	61.0
15	50	{250 cc. 0.1 N Na_2CO_3, 250 cc. 0.1 N Na_2SO_4}	24	10	10.21	8.16	24.40	61.0
16	50	{50 cc. 0.1 N Na_2CO_3, 450 cc. 0.1 N NaCl}	24	10	2.22	1.76	5.31	2.0
17	50	{50 cc. 0.1 N Na_2CO_3, 450 cc. 0.1 N Na_2SO_4}	24	20	0.44	0.32	1.05	2.0

humus were also calculated. In this case 1 cc. of 0.1 N $KMnO_4$ was found to correspond to 0.0008 gm. oxygen, or to 0.002385 gm. soluble humus.

The other method of determining the quantity of dissolved humus was the colorimetric method of Lovibond, used in brewery practice. The set of

colored standard glasses compared fairly well with the brown-colored soil solutions. At first glance (table 4) no direct correlation seems to exist between the amount of organic matter and the colorimetric values. This may tend to show that the solvents employed extracted different amounts of colored organic matter. It seems very likely that normal carbonate of soda favored to a high degree the dissolution of dark-colored matter, whereas sodium chloride acted in the opposite manner.

The first three experiments were intended to demonstrate that by treating the soil for 24 hours in a revolving apparatus and then allowing the solution to settle for 48 hours, the equilibrium may be reached. In the corresponding column the time of revolving is given; the time of settling, being equal, was left out of the table. The fourth experiment shows that the smaller the amount of soil used the greater is the amount of dissolved organic matter. The same holds true for experiment 6. The fifth experiment shows that by treating the soil with one-tenth normal sodium carbonate instead of normal solution, the dissolved organic matter hardly differed and the tint of the solution seemed somewhat darker than in the case of the normal solution. Experiments 7, 8, and 9 show that, for the given concentration, the bicarbonate dissolved most, followed by the sulfate, and last by the chloride. But the further examination of the bicarbonate solution was found to contain some normal carbonate, derived from the decomposition of the relatively concentrated solution. In experiment 11, where there was no chance for the decomposition of bicarbonate, the dissolved organic matter was very low and nearly colorless. The other experiments show that the presence of sodium chloride or sulfate, especially in the more dilute concentrations, prevents materially the dissolution of humus. Thus the author's recent experiments seemingly corroborate the theory of Glinka. Nevertheless, practical experiences do not fully agree with the author's idea that in alkali soils the solubility may be solely dependent on the presence of alkaline salts and their relative concentration. A number of alkali soils nearly free from alkaline salts, but rich in soluble humus, could be found. This seems to suggest that here we have to do with a water-soluble humus, which differs in this respect very strikingly from humus of a neutral garden soil, or a "Tschernozem."

Indeed if we treat a neutral prairie soil with normal sodium chloride, until the exchangeable calcium is taken out of the soil, then wash with distilled water, the solution becomes darker, because the calcium cation, which saturated in some way the humus-complex, was exchanged by the sodium cation, giving rise to the formation of humus-dispersoids, or as might be supposed, of sodium-humates, which are likely to be more soluble in water than the calcium-humates. The theoretical question as to whether this might be a purely physical or chemical reaction cannot be discussed further; the fact to be emphasized is that, in alkali soils, the humus might become soluble not only in the presence of normal sodium carbonate, as Glinka suggested, but, if the humus complex is in some respect saturated or changed into a sodium-

humus-complex, this change may convert the insoluble humus into a soluble one. This is done not only by the carbonates of soda, but also by the sulfate or chloride.

Consequently it seems evident that, in alkali soils deficient in carbonate of soda, the humus-complex itself has the nature of changing easily into a colloidal dispersion or true solution, provided only that the concentration of the neutral salts does not reach the limits of coagulation.

Glinka's theory has properly pointed out the difference between the soil-leaching processes in alkaline and acid media, but his discussion treated mostly the humus, the chemical composition of water extracts, and the typical morphology of alkali soils. The latter description was so characteristic, that the similarity between the Russian and the Hungarian alkali soils could easily be recognized. Since many chemical analyses of the Hungarian alkali soils were available, the author was interested to know whether some characteristic differences in the total chemical composition were found by the hydrochloric

TABLE 5

Comparison of the chemical composition of a timber soil and of an alkali soil

HORIZON	TIMBER SOIL		ALKALI	TIMBER SOIL		ALKALI	TIMBER SOIL	ALKALI
	A_1	A_2	A	B_1	B_2	B	C	C
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Na_2O	0.14	0.28	0.55	0.52	0.32	0.44	0.18	0.71
K_2O	0.50	0.55	0.74	0.54	0.62	1.06	0.74	0.75
CaO	0.25	0.27	2.27	0.41	0.66	5.01	0.49	6.43
MgO	0.52	0.32	1.27	0.47	0.45	1.51	0.77	2.34
Al_2O_3	4.36	7.03	5.17	9.49	10.79	6.31	8.46	7.57
Fe_2O_3	3.54	4.22	4.20	5.17	5.15	3.25	4.30	4.20
CO_2	....	....	1.33	....	....	3.84	....	5.31
SiO_2	3.32	4.62	9.61	4.76	4.61	11.59	6.51	5.48

acid extract of the soil made according to Hilgard. Moreover, the author was engaged at this time (in 1914–1916) in the study of the artificial zeolites, made by the alkaline solution of silicic acid and sodium aluminate (19, 20, 21). The author observed a very similar behavior in the colloidal sodium zeolites and in the alkali soils. The corresponding experiments of the Russian investigator Gedroiz were unknown in international literature, though in 1914, at the meeting of the Second International Soil Commission at Munich, when the chemical methods of soil analysis were treated, the theory of Ganssen on the reconstruction of the soil zeolites, based upon the composition of the hydrochloric acid extract of the soil, as well as the importance of the exchange of bases in soils, was discussed to a large extent. As the Russian investigators did not attend the meeting, however, nobody was informed about the experiments of Gedroiz.

If the chemical composition of a timber soil is compared with that of an

alkali soil in its full profile, some characteristic discrepancy as well as a certain correspondence is found. Robert Ballenegger, a Hungarian soil chemist, studied a typical timber-soil from Tenke (1). The corresponding analytical data of his investigations have been compared in table 5 with those of the author's on the alkali soil profile at Békéscsaba.

If the respective values of the acid and alkali soil profiles are compared, the most striking difference is found in the amount of Na_2O and soluble SiO_2. If horizon C is considered as representing the original regolith, out of which the upper soil-horizons A and B resulted, by processes of weathering and leaching, we might conclude that, in the case of acid-leaching, the silicates of sodium underwent a certain decomposition and washing out from horizon A_1 and A_2, and accumlated in horizon B_2 and B_1. On the contrary, in the alkali soil profile there is no washing out, rather an accumulation of sodium in horizon A,

TABLE 6

Chemical composition of hydrochloric extract of different soil horizons

NUMBER OF SOIL-HORIZON	1	2	3	4	5	6
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Na_2O	3.90	3.38	2.73	1.26	1.93	2.22
K_2O	0.36	2.01	1.76	1.37	1.42	2.03
CaO	0.36	0.37	0.54	2.09	2.06	2.11
MgO	1.00	1.79	1.42	1.76	1.29	1.91
Fe_2O_3	4.64	6.90	8.38	5.42	5.20	7.42
Al_2O_3	8.20	11.91	10.84	10.22	8.99	14.28
SO_3	0.27	0.28	0.19	0.01	.....	0.03
P_2O_5	0.08	0.08	0.12	0.13	0.12	0.10
CO_2	.....	0.01	0.28	0.14	0.20	0.22
SiO_2	22.76	28.61	23.78	17.78	17.07	27.14
Loss on ignition	5.91	5.98	4.86	5.20	5.19	6.65
Insoluble residue	52.84	39.58	45.15	55.45	56.62	35.99

though the soluble SiO_2 accumulated in horizon B. This might be explained by the supposition that the alkali silicates accumulated in some manner in the alkali soil in the uppermost horizon A. As a similar accumulation of alkali silicates has been found by the author in other alkali soils, a more thorough investigation of the characteristics of alkaline soil weathering and leaching was undertaken in a most typical soil-profile at Hortobagy, one of the largest portions of alkali land in Hungary. Samples were taken in 1914 from the following soil-horizons:

1. Surface-horizon A, eluvial, ash gray colored, total salt content 0.8 to 1.0 per cent, reaction neutral to phenolphthalein; 10 to 30 cm. deep.
2. Horizon B, accumulation horizon, with more or less irregular columnar structure, dark-colored, impervious, very plastic when wet, and cracked when dry. Total salt content 1.0 to 1.2 per cent, neutral.

3. Upper ferruginous horizon, total salt 0.3 to 0.4 per cent, sodium carbonate 0.02 per cent.

4. Calcareous horizon, very hard and rich in concretions. Total salt 0.20 to 0.25 per cen , sodium carbonate 0.03 per cent.

5. Second ferruginous horizon, total salt 0.15 per cent, sodium carbonate 0.02 per cent.

6. Clay underground horizon, somewhat sandy, light blue-gray color, total salt 0.10 to 0.15 per cent, sodium carbonate 0.07 per cent.

The chemical composition of the hydrochloric extract made according to Hilgard is recorded in table 6.[2]

If the insoluble residue is considered, two accumulation horizons are found here—2 and 6. In full harmony with that, two maxima are found for each soluble constituent. It is seen at once, that here again the sodium is concentrated in the uppermost horizon, as in the other alkali soils. It seemed very instructive to separate the whole profile into two parts; the three upper horizons representing a different genesis from the three underlying horizons. We have all evidence to suppose that the alkaline soil-weathering and leaching reached approximately to the fourth horizon, and that beneath, a typical profile of acid soil weathering and leaching is found. The only deviation is found in the CaO-maximum in the fourth horizon which might be easily attributed to the posterior leaching from the alkaline horizons. This statement coincides with the historical fact, that some 100 years ago the whole territory on the Hortobagy was more or less swampy, in other words, under acid soil weathering and leaching conditions. Only later, when the regulating of the Tisza River and the drainage of the inundation territories were begun, did the former swampy lands, by becoming temporarily dry, give rise to the formation of alkali soil.

The chemical characteristics of a soil are seen in a better light when the new terminology of soil analyses[3] is used. A short report in English was published in 1912 (17) and in 1915 (19). The advantage and application of the method were also pointed out. The respective values are summmarized in table 7.

The relatively high amount of the total gram-equivalents of the positive constituents dissolved by the concentrated hydrochloric acid prove that we have to do with a soil-profile of an arid climate, and the fluctuation of these values through the whole profile confirms again the theory that, in the process of leaching of this soil we may assume the presence of two periods. The effect of the earlier leaching period extended down horizon 6, whereas the second leaching period influenced the soil only to horizon 4, the accumulation-horizon of the latter being horizon 2. From the relatively high amount of the soluble silica, we might conclude that the weathering of the mineral part was a very strong one and especially that horizon 2 and 6 are rich in decomposed silicates.

[2] The analysis was made by Geza Binder-Kotrba of this laboratory.

[3] Suggested by the author in 1905, at the meeting of the chemical and mineralogical section of the Hungarian Society of Natural Sciences (13) and in 1909, at the Seventh International Congress of Applied Chemistry in London (15).

We know that the concentrated hydrochloric acid may attack not only the weathered minerals, but also the most unaltered silicates (18, 19), to a smaller degree and only in a highly disintegrate condition. The relatively large amounts of the total gram-equivalents showed at the same time that, although there was a double leaching, the latter was not so effective as in a humid climate, where the total gram-equivalents of the mono- and bivalent positive constituents range around 6 per cent and about 20 per cent in arid soils as in the present case (13,17). The same conclusion may be drawn from the very small portion of carbonate-equivalents.

TABLE 7

Influence of hydrochloric acid upon the displacement of positive and negative ions from the soil

	SOIL HORIZON NUMBER					
	1	2	3	4	5	6
Total positive gm. equivalents, dissolved by conc. HCl in 100 gm. soil	0.8517	1.2124	1.1814	1.0354	0.9531	1.40
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Soluble SiO_2	22.76	28.61	23.78	17.78	17.07	27.14
Insoluble residue	52.48	39.58	45.15	55.45	56.62	35.99
Na^{I}	14.77	8.99	7.45	3.93	6.53	5.11
K^{I}	0.90	3.52	3.16	2.81	3.16	3.07
Ca^{II}	1.51	1.09	1.63	7.20	7.70	5.36
Mg^{II}	5.82	7.32	7.22	8.43	6.72	6.76
Fe^{III}	20.47	21.39	26.66	19.67	20.50	19.89
Al^{III}	56.53	57.69	53.88	57.96	55.39	59.81
SO_4^{II}	0.79	0.57	0.40	0.02	.....	0.05
CO_3^{II}	.....	0.04	1.08	0.62	0.95	0.72
PO_4^{III}	0.39	0.28	0.43	0.53	0.53	0.30
SiO_4^{IV}	98.82	99.11	98.09	98.83	98.52	98.93
Surplus of soluble SiO_2	10.08	10.50	6.31	2.36	2.92	6.23
Total of mono- and bivalent positive constituent equivalents	23.00	20.92	19.46	22.37	24.11	20.30
Total of the trivalent positive constituent equivalents	77.00	79.08	80.54	77.63	75.89	79.70
Total negative equivalents—SiO_4^{IV}	1.18	0.84	1.91	1.17	1.48	1.07

If we now consider the percentage equivalent of the single constituents, we observe that sodium plays the leading rôle, especially in the three upper horizons, whereas the opposite is found in respect to calcium which, accumulating mostly in the lower three horizons, shows at first glance whether in alkali soil, the sodium has taken its place, later exceeding the mono- and bivalent cations ordinarily found in arid soils (13, 17). The author was, at the same time, engaged in the study of some artificial calcium zeolites prepared in the labora-

tory (19, 20, 21). In experimenting with these zeolites, the author observed several times, that the calcium zeolites behaved like a granulated mass, with a good filtering capacity; the respective sodium zeolites, on the contrary, represented a very dispersed and diffusible mass of a bad filtering capacity. As the difference between the two compounds consisted chiefly in the different cations, which could be exchanged very quickly and nearly absolutely by the neutral salt solution of the respective cations, the same process was repeated with some alkali and with some non-alkali soil. The method used for this investigation was a mere provisory one, consisting of the treatment of 50 gm. of air-dry soil with 800 cc. of a 10 per cent solution of ammonium-nitrate. As the alkali soil contained more or less water-soluble alkali salts, another 50-gm. portion of the soil was treated with pure water in the same manner. In table 8 the total amount of the bases determined in the ammonium salt solution is given; in table 9 the data on the water-solution are given; and in table 10 the differences of the two determinations calculated for each hundred grams of air-dry alkali soil of the six horizons of Hortobagy are reported. In the lower part of table 10 the respective values are calculated in millimol-percents.

If the absolute quantities of the exchangeable bases are compared, it becomes evident that the sodium dominates in the upper horizon, and decreases downwards. The calcium on the other hand reaches its maximum in the lowest horizon and gradually decreases toward the upper horizon. It seems very likely, that the sodium cation displaced the calcium cation. As the soil is at the present time infiltrated with sodium salts one is justified in supposing that the soil contains a silicate complex similar to the one prepared by the author under different conditions as well defined artificial zeolites. When these facts were first published (1915) nothing was known of the similar experiments published in Russian by Gedroiz just as that author could not have any idea of the author's Hungarian and German aforcited publications (19, 20, 21). It would be a pleonasm to emphasize intensively the occurrence of this base exchange in alkali soils. If the fact is considered, that three investigators like Gedroiz, Kelley, and the author, very far distant from one another, and under very different conditions, quite independently from one another, and starting from different evidences, concluded in full agreement on the same point; that *in the alkali soils a considerable part of the exchangeable cations is represented by sodium and this combined sodium may be responsible for the bad physical properties of the alkali soil,* it is evident that in this respect the theory of Hilgard again needs some correction, and that the reclamation of alkali lands is not simply a soil-washing process. The theory of Glinka needs also to be corrected in regard to the exceptional rôle of normal sodium carbonate. According to the evidence reported above, *the conversion of a soil into an alkali soil can be done by any neutral sodium salt.*

The author cannot agree with the classification of Gedroiz in regard to the terms saline and alkaline soil. Though chemically true, his distinction does not

TABLE 8

Bases exchanged in 50 gm. of alkali soil by 800 cc. of 10 per cent NH_4NO_3

SOIL HORIZON NUMBER	CaO		MgO		K_2O		Na_2O	
	mgm.	*milli-mol*	*mgm.*	*milli-mol*	*mgm.*	*milli-mol*	*mgm.*	*milli-mol*
1	73.1	1.30	27.1	9.67	45.1	0.47	298.8	4.81
2	64.6	1.15	162.8	4.03	269.2	2.84	247.2	3.98
3	152.2	2.71	180.1	4.46	196 8	2.08	173.9	2.80
4	275.4	4.90	52.0	1.28	100.3	1.06	88.8	1.43
5	296.8	5.29	127.4	3.15	34.4	0.36	8.4	1.13
6	346.5	6.17	49.3	1.22	84.3	0.89	74.3	1.19

TABLE 9

Amount of water-soluble material in 50 gm. of alkali soil

SOIL HORIZON NUMBER	K_2O		Na_2O		SO_3	
	mgm.	*milli-mol*	*mgm.*	*milli-mol*	*mgm.*	*milli-mol*
1	25.0	0.26	127.9	2.06	48.0	0.59
2	4.8	0.05	153.6	2.47	81.6	1.02
3	180.8	0.91	116.8	1.88	62.4	0.77
4	136.0	1.44	78.4	1.26	32.5	0.40
5	26.2	0.27	6.9	0.11	15.4	0.19
6	56.0	0.59	71.2	1.14	41.6	0.51

TABLE 10

Exchangeable bases in the alkali soil at Hortobágy

SOIL HORIZON NUMBER	CaO	MgO	K_2O	Na_2O	TOTAL
	Milli-mols in 100 gm. of soil				
1	2.60	1.34	0.42	5.50	9.86
2	2.30	8.06	5.58	3.02	18.96
3	5.42	8.92	0.34	1.84	16.52
4	9.80	2.56	.....	0.34	12.70
5	10.58	6.30	0.18	0.04	17.10
6	12.34	2.44	0.60	0.10	15.48
	Milli-mol per cent				
1	26.4	13.5	4.3	55.8	100.0
2	12.1	42.5	29.4	16.0	100.0
3	32.8	54.0	2.0	11.2	100.0
4	77.1	20.0	.....	2.9	100.0
5	61.9	36.8	1.0	0.3	100.0
6	79.7	15.8	3.9	0.6	100.0

point out the fundamental character of all alkali soils—that they are the results of an arid or semiarid climate, and if in some respects they may correspond to the littoral salines, nevertheless, they represent as a whole a different and typical soil type. It is known from the experiments of Hissink that among the saline marsh lands soil layers similar to the true alkali soils are found. He found also that, in this case, the amount of exchangeable sodium becomes rather high in comparison with the other polders,[4] but the polder soil has its own character whether it is a saline or not; although it always represents *an unsaturated soil* as a result of the *soil-weathering in an acid medium* and under *permanent abundance of humidity*. On the contrary *an alkali soil, if truly alkaline or saline, is always the result of a greater or less accumulation of the monovalent cations;* it gives a *higher saturated condition* to the whole soil profile even in the case shown above, when the earlier period of the soil-forming conditions favored an acid weathering and leaching. The question of the degree of saturation of the different soil types will be treated in a later report, as the author is not now able to give exact empirical data on the full question under consideration. But principally the author cannot agree with any conception whereby some single horizons or layers are taken out of the soil profile and treated as some typical soil. That is the great merit of the Russian agronomists who have proved that *for the proper characterization of a soil or even of a soil type, it is not enough to study the surface or any other single horizon of the* soil profile, but the genesis of the whole profile must be considered always. According to the definition of Gedroiz it is possible that the surface horizon of a soil profile might be alkaline, and a lower horizon of the same soil profile might be classified as a saline, and that another horizon of the same profile might be characterized as alkaline-saline. Therefore, it seems better to *reserve the term "alkali soil" for a distinction of the terrestrial salty soils resulting from an alkali medium in the above sense, i.e., under soil conditions of temporary abundance of humidity*, as pointed out by Glinka and the author. On the other hand the term "saline soil" is applied to soils infiltrated for some reason, with a salt solution, independently of the climatic and genetic soil conditions. In this definition the latter has a general and a broader sense than the term "alkali soil," which represents but a typical class of the saline soils in dry climates. This is also in full agreement with the original definition of Hilgard, the author of this term; but this terminology does not interfere with the genetic consideration of the whole soil profile, the characteristics of which were exemplified by that of the alkali soil at Hortobagy.

As a check, the same experiments were carried out with a soil at Keszthely. The total analysis of the hydrochloric soil extract made according to Hilgard is given in table 11. It might be stated that, as a whole, sodium plays a very inferior, almost negligible rôle, in the full profile. The gradual decrease in insoluble residue indicates that the mineral matters decomposable by strong

[4] *Polder* is a littoral endiked soil in Holland, but not marshland, formed by cultivation and soil-washing of the salty "Uvelder" soils.

TABLE 11

Results of analysis of hydrochloric acid extract of the soil at Keszthely

NUMBER AND DEPTH OF THE SOIL HORIZON	1 0 TO 25 CM.	2 25 TO 50 CM.	3 50 TO 60 CM.	4 60 TO 70 CM.	5 70 TO 150 CM.
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Na_2O	0.19	0.26	0.19	0.08	0.18
K_2O	1.49	1.46	1.26	1.62	0.96
CaO	4.23	2.27	2.30	9.68	19.46
MgO	2.19	2.28	2.00	2.80	6.28
Fe_2O_3	3.90	4.26	3.62	3.11	2.27
Al_2O_3	5.58	9.64	11.95	13.19	8.55
SO_3	0.04	0.06	0.05	0.06	0.03
P_2O_5	0.22	0.27	0.19	0.12	0.12
CO_2	1.94	3.64	3.94	10.51	21.86
SiO_2 soluble	17.29	19.92	22.69	19.53	12.28
Loss on ignition	5.39	1.77	3.85	2.63	.....
Insoluble residue	56.56	53.98	47.82	36.86	27.69
Total	99.02	99.81	99.86	100.19	99.68

TABLE 12

Influence of hydrochloric acid upon the displacement of positive and negative ions from the soil at Keszthely

	SOIL HORIZON NUMBER				
	1	2	3	4	5
Total of the positive gram equivalents, dissolved by conc. HCl in 100 gm. of soil	682.15	959.50	1051.90	1412.42	1618.85
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Soluble SiO_2	17.29	19.92	22.69	19.53	12.28
Insoluble residue	56.56	53.98	47.82	36.86	27.69
Na^{I}	0.90	0.86	0.58	0.18	0.34
K^{I}	4.63	3.23	2.54	2.44	1.27
Ca^{II}	22.11	8.44	7.80	24.43	42.80
Mg^{II}	2.83	11.78	9.43	9.83	19.25
Fe^{III}	21.49	16.69	12.93	8.28	5.28
Al^{III}	48.04	59.00	66.72	54.84	31.03
SO_4^{II}	0.14	0.15	0.12	0.11	0.05
CO_3^{II}	1.39	1.21	0.78	0.37	0.32
PO_4^{III}	12.51	16.69	16.47	32.73	59.40
SiO_4^{IV}	85.96	81.95	82.63	66.79	40.23
Surplus of soluble SiO_2	8.45	8.07	9.59	5.31	2.46
Total of the mono- and bivalent positive constituent equivalents	30.47	24.31	20.35	36.88	63.69
Total of the trivalent positive constituent equivalents	69.53	75.69	79.65	63.12	36.31
Total negative equivalents—SiO_4^{IV}	14.04	18.05	17.37	33.21	59.77

HCl, though very high in amount, were leached out of the upper soil horizon. The chemical characteristics of this profile according to the author's system are given in table 12.

The high amount of the total equivalents places the soil among those of arid climate, though all evidences point to the fact that in the earlier period of soil formation there was a time when the climate was more wet, and that this resulted in the washing down of the bivalent cations. This is generally the case in forest soils, and it is very likely that originally this land was overgrown with wood. After the soil was cultivated surface evaporation gave the more mobile soil constituents opportunity to migrate to the surface. Indeed a marked accumulation of sodium, potassium, and calcium equivalents characteristic of arid soils is found in the surface horizons. We see here again a certain similarity to the origin of the alkali soil at Hortobagy, with the only

TABLE 13

Exchangeable bases in the soil at Keszthely

SOIL HORIZON NUMBER	CaO	MgO	K_2O	Na_2O	TOTAL
	Milli-mols in 100 gm. of soil				
1	14.84	0.96	0.152	0.376	16.328
2	13.64	0.54	0.134	0.408	14.678
3	16.58	2.42	0.158	0.066	19.224
4	14.16	2.50	0.108	0.344	16.932
5	12.86	0.72	0.204	0.222	14.006
	Milli-mol per cent				
1	90.88	5.87	0.93	2.30	100
2	92.92	3.67	0.91	2.75	100
3	86.24	12.58	0.82	0.34	100
4	83.74	14.76	0.63	2.03	100
5	91.81	5.14	1.45	1.58	100

difference that, in the latter case, the second period was arid, but intersected with temporary humid soil conditions, and that this resulted in the formation of a typical alkali soil profile; on the other hand, in the case of the soil at Keszthely, the earlier humid period was succeeded by an artificial dry period that resulted from bringing under cultivation the former forest land. It is easy to understand that destroying the forest and turning it over to regular agriculture, favor surface evaporation, which goes hand in hand with the accumulation of the more mobile soil constituents.

The exchangeable bases were determined as previously, and the respective data are given in table 13.[5]

If these data are compared with those in table 10, the conclusions may be

[5] The determinations were made by the author's former assistants Stephen Száraz and Coloman Gehring.

drawn in the case of the soil atKeszthely, that the leading exchangeable cation over the whole profile is calcium, figuring the millimol percentage at an approximate value of 83 to 93, the magnesium coming second but with a much smaller value, and potassium and sodium representing hardly 1 or 2 per cent. Here we have just the opposite from that found in the profile of the alkali soil, where the calcium was gradually displaced by sodium then by potassium and magnesium.

When the author first obtained these results in 1915, he did not know of the investigations of Hissink, Gedroiz, and Kelley on the exchangeable cations in

TABLE 14

Exchangeable bases in the soils

SOIL QUALITY		CaO	MgO	K_2O	Na_2O	TOTAL
		Milli-mols in 100 gm. of soil				
Bad alkali, impermeable	Hortobágy 1	2.60	1.34	0.94	9.62	14.50
	Békéscsaba 5	8.32	3.86	0.14	7.30	19.62
	Mezőhegyes	17.65	2.54	0.55	4.68	25.42
Mild alkali permeable	Békéscsaba 1	13.58	5.18	0.44	.....	19 20
	Békéscsaba 2	11.22	2.32	0.50	.....	14.04
	Békéscsaba 11	11.94	4.16	0.72	0.16	16.98
Non-alkali permeable	Keszthely 1	15.96	1.75	0.33	0.19	18.23
	Keszthely 22	15.18	1.82	0.41	0.12	17.53
		Milli-mol per cent				
Bad alkali impermeable	Hortobágy 1	17.93	9.24	6.48	66.35	100
	Békéscsaba 5	42.41	19.67	0.71	37.21	100
	Mezőhegyes	69.43	10.00	2.16	18.41	100
Mild alkali permeable	Békéscsaba 1	70.73	26.98	2.29	.....	100
	Békéscsaba 2	79.92	16.52	3.56	.....	100
	Békéscsaba 11	70.32	24.50	4.24	0.94	100
Non-alkali permeable	Keszthely 1	87.56	9.61	1.82	1.01	100
	Keszthely 22	86.55	10.38	2.36	0.41	100

neutral and acid soils, (2, 3, 6, 7, 8, 9, 10). His own original publications in Hungarian date back to 1917. In the author's inaugural dissertation in 1916, at the Academy of Sciences at Budapest and at the meeting of the chemical and mineralogical Section of the Hungarian Society of Natural Sciences, he reviewed his first experiments in this field, showing some characteristic evidences between the permeability of different soils and the relative amount of different exchangeable cations (19, 20). The respective values are given in table 14.

Among the soils of a bad filtering capacity, a gradual displacement of calcium by sodium is found, whereas in the case of good permeability, even if the soil itself may be of an alkali character, the relative value of the sodium millimols among the exchangeable bases seems to be quite negligible. This fact was indeed the starting point of the author's further studies in that line. At that time the experiments of Hissink and of Kelley (6, 10) were not yet published, and those of Gedroiz in Russian were unavailable. It is true, on the other hand, that the author's publications in Hungarian were useless to the aforementioned investigators. After all, there is now plenty of evidence to show that the dominant rôle of the exchangeable calcium in neutral and acid soils, and also of the fact that, in the case of alkali soils, its place may be taken partly or fully by the cation sodium.

The author does not intend further to discuss here the principal question: *whether the displacing of these cations represents a true chemical reaction.* Based on his experiments on the artificial zeolites, and various other investigations, not yet published, the author is inclined toward the chemical explanation of this phenomenon; he hopes to be able to give a detailed confirmation of this view in the near future.

In summing up the theory of the origin of alkali soils, it may be stated that *alkali soils may originate under arid and semiarid conditions, where in the past there is in the soil a temporary abundance of humidity intersected by dry periods.* In the case of the Hungarian alkali lands that this was effected is historically indicated by the large inundational territories of earlier times, resulting partly in swampy and peaty lands and partly in alkali soils. Another combination of favorable conditions for the origin of alkali soils was the collection of seepage water in the lower basins and water rivulets in the large sandy territory between the two main rivers, the Danube and the Tisza (Theiss), the bottom of these lowlands being always impervious clay or calcareous hardpan. In both cases there was an opportunity for the sodium salts to accumulate on the surface, and *the more or less concentrated sodium salt solutions reacted with the zeolite-humate-complex in the soil in replacing in some degree the calcium, magnesium, and potassium by the sodium cation.* The degree of this replacement was different according to local circumstances; it was evidently dependent not only on the concentration of the same solution lodging in the soil repeatedly but, also on the fact that the ratio of the cations in the solution, and the original composition of the solid phase of the soil might regulate the equilibrium of the whole reaction, which according to Ramann (11) *follows the law of mass action.* As far as the genesis of the alkali soils in other parts of the world can be observed, similar considerations can be traced. It is hoped that the close coöperation of the numerous investigators engaged in this line of work will insure quicker solution of the problem. In this respect the author should like to open here the discussion on the origin of the different alkali soils of the world. The discussion should treat the following questions:

1. Is it right to generalize the thesis that, for the formation of alkali soils, in the above sense, three factors are responsible; namely, arid or semiarid climate, an impervious subsoil or hardpan, and temporary abundance of humidity in the soil, intersected with dry periods?

2. Is it right to treat the alkali soils as soils in which the exchangeable sodium becomes to some extent a ruling factor, or may it not be that in some cases, other cations, like potassium, and magnesium are displacing to a more or less degree the exchangeable calcium?

3. What is the typical morphological and chemical character, in the above discussed sense, of the typical alkali soil profiles in different parts of the world? Which factors of the soil formation may chiefly influence this evolution?

As the salty soils of humid climate are of different origin, but have some resemblance in their chemical and physical character, they should be treated under a separate heading.

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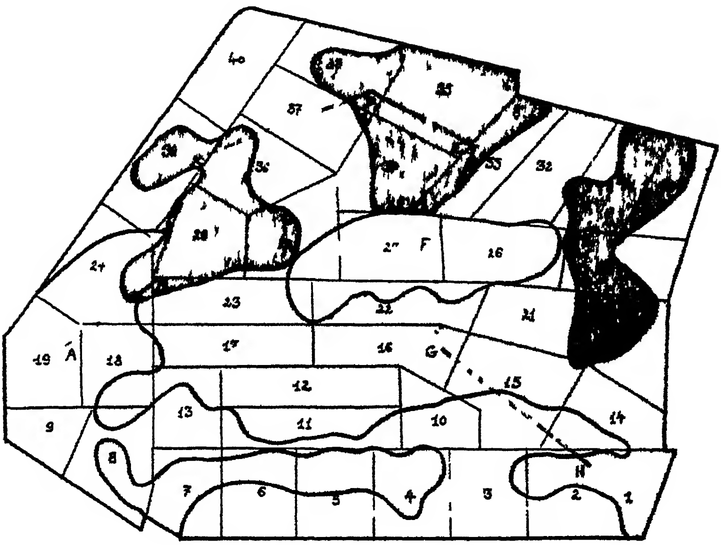
PLATE 1

Distribution of the Total Salts to an Average Depth of 120 cm. on Alkali Land



Total salt content

I 0–0.10% II 0.10–0.25% III 0.25–0.50%

PLATE 2

FIG. 1. How the vertical distribution of the four typical soil-horizons fluctuates in a cross-section through the different salt classes, along the line ABCDEFGH shown in plate 1.

FIG. 2. Corresponding salt content of the four soil-horizons of figure 1.

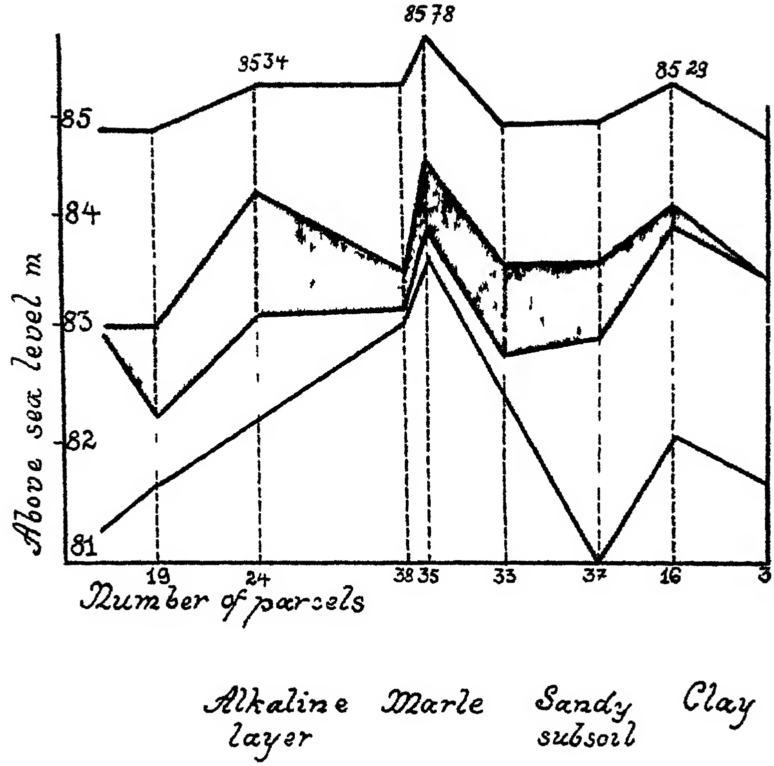

8578
8534
8529
85
84
83
82
81
Above sea level m
19
24
38
35
33
37
16
3
Number of parcels
Alkaline layer
Marle
Sandy subsoil
Clay

FIG. 1


Total salt
Sodium carbonate

DO COLLOIDS EXIST AS A COATING AROUND THE SOIL GRAINS

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It appears to be the general belief that the colloids in the soil exist as a coating around the soil grains or as an encasing gel (2, 4, 6). As the subject, however, seems never to have received a direct and purposeful study, this belief is founded more on supposition than on experimental facts. This supposition was probably based upon the old idea that the colloidal matter in the soil was small, rarely over 1.5 per cent according to the claims of Schloesing (7) which persisted until recently. The inference was logical, therefore, that this small amount of colloidal matter would be spread as a coating around the soil grains. Recent studies (1, 3) have revealed, however, that the colloidal content of soils is very large, amounting to more than 70 per cent in many typical heavy clays, more than 50 per cent in some clay loams, and more than 15 per cent even in typical sandy loams. It becomes at once apparent, therefore, that all this colloidal mass cannot exist entirely as a coating around the soil grains, especially in the clays and clay loams. In view of these new revelations, it is of considerable interest and importance to ascertain how the colloidal complex really exists in the soil. It is the object of this paper, therefore, to present data bearing on the subject. It must be stated at the outset, however, that the subject presents many difficulties in the way of arriving at an absolute conclusion as to the actual constitution of the colloidal material in the soil, but the observations and experimental data presented herewith tend to throw much light on the subject.

EXPERIMENTAL

The problem has been studied principally by two different methods: first, by optical examination; and secondly, by the heat of wetting method.

Optical Examination

The soils were examined both by the naked eye and under the microscope. Both types of examinations revealed the fact that the coarse soil material, such as the gravel and the coarse and some of the fine sand, was not always encased in a coating of colloidal material. On the contrary, in almost all the mucks and peats examined in dry condition, the sand present was clean. When a wet block of muck or peat was allowed to dry intact, the sand particles could easily be seen with the naked eye enmeshed in or stuck to the or-

ganic material or colloid, but upon gentle crumbling of the blocks, the sand particles would fall apart as independent material and with a clean surface. On the surface of mucks and peats in the field the clean sand particles could readily be seen shining.

The optical examination of the mineral soils revealed, in general, the same facts as in the case of the organic soils. In sandy soils the larger sand particles could be readily seen, even with the naked eye, to be mostly bare and not covered with a coating of gel. In some cases these larger sand particles were covered with a coating, which would come off on the slightest rubbing between the fingers, indicating that the force with which a coating may be held around a sand particle is probably not very great. Sand particles small enough to pass a 100-mesh sieve could be readily seen to be bare and with a white surface.

In the heavier classes of soils—including the loams, the silts and the clays, most of the gravel, and the large and medium sands—the solid particles also appeared practically devoid of a gel coating. Whatever coating they did have, came off rather readily. When these soils were allowed to dry in solid masses and were then broken in two or more pieces, the gravel and the sand could be easily seen on the broken sides sticking to the mass and would come off rather easily and bare. Where the solid particles were extremely fine and the amount present was not so large as in clays, they were not so apparent to the naked eye but under the microscope they could be seen in most cases.

These find sand particles were more or less completely enmeshed in the clay or colloidal material, but, as will be shown subsequently, even under these conditions they also tended to fall apart more or less independently of the colloidal material.

Heat of wetting

The observations made under the optical examination were tested by means of the heat of wetting method. It was reasoned that if the sand particles were more or less devoid of a colloidal coating, their heat of wetting ought to be very low. The difficult problem that presented itself, however, was how to separate the sand particles from the colloidal material or from the rest of the soil mass. Two procedures were attempted: one consisted of picking out, by means of forceps, the sand particles that were visible to the naked eye, and the other, of sieving the soils. The first method was practical and quite satisfactory with the sands, sandy loams, loams, and clay loams, but not always with the heavy clays or soils in which the sand particles were extremely small and dust covered. With the second method, the soil was sieved without grinding, if possible, and where necessary the soil mass was crumbled gently. Soils taken from the surface field were first allowed to dry and then were passed through a 10-mesh sieve to separate them from stones and gravel. The soils that were dried hard were either pressed with the hand on the 10-mesh sieve until they crumbled and went through it or they were broken up in a mortar

into crumbles. After a soil had passed a 10-mesh sieve it was well mixed and then sieved through a 200-mesh sieve. The material that went through the 200-mesh and that which remained behind were considered different and their heats of wetting were determined. Table 1 contains the results obtained on the sand particles picked out with forceps and table 2 contains the results on the soils sieved.

TABLE 1

Heat of wetting of picked sand particles from different soils

	CALORIES PER GRAM
Norfolk sandy loam	0.13
Fresno fine sandy loam	0.10
Corville sandy loam	0.11
Chester loam	0.19
Crowly silt loam	0.12
Amarillo fine sandy loam	0.21
Rhode Island sandy loam	0.10
Pennsylvania silt loam	0.11
Tennessee silt loam	0.15
Michigan clay loam	0.16
Illinois black clay loam	0.23

TABLE 2

Heats of wetting of material passing 200-mesh sieve and of that remaining behind

	SOILS	MATERIAL PASSING 200-MESH SIEVE	MATERIAL REMAINING BEHIND
		calories per gram	*calories per gram*
1	Norfolk sandy loam	3.94	2.05
2	Fresno fine sandy loam	1.32	0.92
3	Corville sandy loam	1.03	0.57
4	Amarillo fine sandy loam	6.54	3.41
5	Rhode Island sandy loam	2.78	2.47
6	Pennsylvania silt loam	2.54	3.09
7	Ohio silt loam	2.07	2.35
8	Michigan clay loam	4.05	4.98
9	Illinois clay loam	3.24	4.04
10	Michigan Ontonagon clay loam A_1	3.74	4.14
11	Michigan Ontonagon clay loam A_2	3.51	4.95
12	Michigan Ontonagon clay loam B_1	6.30	6.92
13	Red clay	2.30	3.41
14	California adobe clay	5.70	6.20

An examination of the results in table 1 shows immediately that the heat of wetting of the sand particles which can be easily separated from the soils, is practically negligible, which goes to prove that these sand particles have practically no colloidal coatings around them. The slight heat of wetting that is

shown is due mainly to the dust of the finer material adhering to their surfaces, and also to some soil particles taken in by mistake because of the difficulty of separation. If it were not for these two latter factors, the heat of wetting would have been nil, almost the same as that of quartz sand. The conclusion of these results would seem to be, therefore, that as a general rule the gravel, the large sands, and in some cases the fine sands, either are not covered or do not stay permanently covered with a colloidal coating. There are undoubtedly exceptions, but in general this conclusion would hold.

The results in table 2, show that with the exception of three cases out of fourteen, the heat of wetting of the material that went through the 200-mesh sieve is greater than that which remained behind. In other words, the material that remained behind in the 200-mesh sieve, and contained in many cases the gravel and the coarse sand, gave a higher heat of wetting than the fine material that could pass the 200-mesh sieve, except in the three cases mentioned. The difference in some cases is quite appreciable; for instance, on Ontonagon clay loam A_2 the 200-mesh sieved material gave a heat of wetting of 3.51 calories per gram as against 4.95 calories of the coarse material. In red clay the heat of wetting was 2.30 calories for the fine material and 3.41 calories for the coarse material. The remarkable thing is that the coarse material in some soils, as in Rhode Island sandy loam, contains as much as 25 per cent of coarse gravel and sand which itself had no heat of wetting, and yet the total coarse material gave a higher heat of wetting than the fine which went through the 200-mesh sieve.

The question now is, how can these results be explained. For one thing it is very apparent that the coarse material contains more colloids than the fine material which goes through the 200-mesh sieve. This conclusion seems inevitable because, as has been previously shown (1), it is the colloidal material which is mainly responsible for the heat of wetting. The fine material, therefore, contains a greater proportion of non-colloidal substance, mainly very fine sand, than the coarse portion even though the latter also contains the gravel and the coarse sand, but the larger proportion of colloid out-weighs these coarser substances.

In reference to the constitution of the colloidal material in soils, these results can be most reasonably explained on the hypothesis either that the colloids in the soil do not exist wholly or permanently as a coating around even the small grains, or that they are evenly distributed around the soil grains or throughout the soil mass. If the colloids existed as a coating around the soil grains, especially the smallest, then the fine material which went through the 200-mesh sieve certainly ought to contain more colloids and should give a higher heat of wetting.

The most logical hypothesis under which these results can be explained is that the colloids in the soil exist partly as a coating and partly as an independent component containing various amounts of impurities. Which of these two forms will predominate will depend upon the soil or upon the total

colloidal content present. In the sands, the coating form should be expected to predominate, but because of the poor adhesion between the surfaces of the sand and the colloidal coatings, the latter tend to break off easily under tillage process. In the sandy loams, loams, silts, and clays, the colloids as an independent component would tend to predominate. In these soils there may be compound particles which are composed largely of colloidal material, and which, because of the great adhesive—cohesive and cementing forces of the colloidal particles, are hard and almost unbreakable when dry.

The results obtained on the heat of wetting of the fine and coarse material as already considered, fit very well the above hypothesis, and are explainable by it. For instance, the reason that the coarse material gives a higher heat of wetting than the fine material which passes the 200-mesh sieve is because the coarse material contains a large portion of the colloids as an independent component or as compound colloidal particles. These compound colloidal particles together with that portion of the colloids which may exist as a coating give the coarse material a higher percentage of colloidal material than they do the fine material. Since large portions of the colloids exist as compound particles and are quite obdurate to breaking they do not pass through the 200-mesh sieve. The fine material that passes the 200-mesh sieve is composed of very fine sand, more or less coated with colloids, of some silt, and of some colloidal dust. The colloidal dust does not predominate in the fine material as do the colloidal compounds in the coarse material, and consequently the heat of wetting in the former is less than in the latter. Considering that the fine sand and silt passing the 200-mesh sieve present an enormous surface, it becomes evident that if this surface was well coated with colloids, the heat of wetting should be much greater in the fine than in the coarse material.

The above hypothesis also tends to explain the results that are exceptions to the general trend. Table 2 shows that the three exceptions of a greater heat of wetting in the fine than in the coarse material, are confined to the sandy soils. It was stated above that the adhesive forces between the surfaces of the sands and the colloids are not so great as the cohesive forces of the colloidal particles. The colloidal coating of the sand particles, therefore, can easily break off and if in a thin layer, will crumble into fine particles on slight disturbance. When these sandy soils, therefore, are sieved, the fine colloidal particles will pass through, and the proportion of the colloids to the fine sand that also went through the sieve, is greater than that of the colloids to the sand remaining behind. The result is that the fine material has a higher heat of wetting than the coarse, as the results show.

It might be argued that the difference in the heat of wetting of the fine and coarse material as separated by the sieve does not prove that all the colloids are not present in the soil as a coating around the soil particles, because in the handling and preparation of the soil for sieving, the colloidal coating could break off or crack from the soil grains and thus give the results obtained. The answer to this argument is that all the handling or treatment that most of the

soils employed received, was merely putting them in the sieve and shaking them gently. But the results of the soils that were merely gently sieved are the same as those where the soils were ground to crumbs. So it does not appear that the handling of the soils is responsible for the type of results obtained.

That the colloidal content of the soils may not and cannot all exist as a coating around the soil grains, is supported very forcibly by the mode of occurrence and the amount of colloids in the soil.

A comprehensive consideration of the actual occurrence of the colloids in the soil reveals immediately the fact that they do not remain where they are formed—in the most rapidly weathering zones of the earth crust. In the humic regions, they have a tendency to move downward with the percolating water, and to concentrate at certain zones or subsoils, so that the latter almost always contain more colloids than the surface soil. It is very well known, of course, that when the colloids are dispersed, as they are by repeated washing or by other treatments, they will pass through even a very fine filtering medium, such as filter paper. The colloids from the surface soils, therefore, as a pure colloid can easily pass through a column of soil and concentrate in the subsoil or B horizon. When they concentrate at the lower horizons, they can do so in an irregular manner: in the capillary channels of the soil, at the edges of particles, etc. These percolating colloids do not necessarily concentrate, therefore, around the soil grains with the latter as a nucleus. Even in the ideal cases where it is imagined that the colloid gel is formed around the original mineral particle by the decomposition and hydrolyses process, it cannot be said that this gel will premanently stay there. It must always be remembered that the soil is a dynamic and not a static system.

The clays which are nearly all colloids (1, 5) are formed principally under still water. The non-colloidal and some colloidal material will settle first and the purer colloidal last. This last colloidal material certainly does not exist as a coating. If this clay soil should be put under cultivation, it is not reasonable to suppose that the colloidal part will be finally distributed as a coating around the soil grains, especially when it is remembered that the colloids exist in the soil not as sol but almost wholly as gel.

SUMMARY

A study has been made to determine the constitution of the colloids in the soil. The old idea has been that the colloidal content of the soils exists entirely as a coating around the soil grains. This idea probably originated from the old belief that the colloidal content of soils was rarely more than 1.5 per cent. We now know, however, that the amount of colloids in the average soil is more than 70 per cent in many cases.

The experimental results presented in the foregoing study indicate that the colloids in the soil do not exist entirely as a coating around the soil grains, but also as an independent component, either pure or containing different amount of impurities and scattered irregularly throughout the soil mass.

The experimental results and conclusions are strongly supported by a logical consideration of the form and amount of the colloids present in the soil.

Optical examination of soils shows that they contain particles of sand and pebbles of various sizes which are not covered with colloidal gel.

The soil material that goes through 200- and 325-mesh sieves, is not clay. As a rule it contains less clay and colloids than the coarse material remaining behind.

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RELATION OF FINENESS OF GRINDING TO RATE OF SULFUR OXIDATION IN SOILS[1]

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Sulfur as brought from the mine in the crude state by the Frash hot-water process, when cool remains in the lump form. For agricultural use, and especially for use on soils, the crude lump which is usually more than 99 per cent pure, is ground into different grades according to fineness, the very finely ground, being known as "flour sulfur." Since the more finely the sulfur is ground, the more expensive is the process, if coarser material is sufficiently effective, a coarser grinding of sulfur used on soils would be economical.

For many uses also the crude lump sulfur instead of being ground, is melted and distilled for purification. The distillate may be cooled and collected by a certain process in the form of very fine particles, and is known as "flowers of sulfur," or it may be cooled en masse, later to be broken up and ground as in the case of the crude sulfur. The refined and purified sulfur is of course more expensive than the crude sulfur, regardless of grinding, and perhaps is no more effective on the soil.

In this study, different grades of crude sulfur, according to fineness of grinding, were compared. Refined flour sulfur, as well as a composite sample with all degrees of fineness of the crude were also used. The chief study was to determine the rate of oxidation.

Three soils were used in the study, all rather coarse in texture and carrying a good proportion of sand, as is characteristic of areas of light rainfall. Soil 1 is known as Redmond sandy loam and is characteristic of Eastern Oregon soils. Soil 2 is a sandy loam from Klamath Falls, and is characteristic of Southeastern Oregon soils. Soil 3 is a Columbia fine sandy loam from Grants Pass, and is typical of Southern Oregon soils. All the soils are nearly neutral in reaction and in good physical condition. All are fairly productive soils but respond to the use of sulfur on legumes under field conditions.

[1] The work was started on soil 1 by Messrs. Lance and Higby, who were doing some advanced work in soils under the direction of Prof. C. V. Ruzek. S. C. Lance and W. M. Higby together made the analysis of sulfates for the one soil for one month. School closed at that time and the problem was considered of sufficient importance to be assigned to the author for completion. Two other soils were then taken up and the study completed as herein reported.

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TABLE 1

Amounts of sulfur oxidized to sulfates

In 100 gm. of soil

SULFUR MESH	2 WEEKS			4 WEEKS			7 WEEKS			11 WEEKS			19 WEEKS			FINAL SAMPLING		
	Soil number			Soil number			Soil number			Soil number			Soil number			Soil number		
	1	2	3*	1	2	3*	1	2	3*	1	2	3*	1	2	3*	1	2	3*
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*per cent*	*per cent*	*per cent*
100	0.0090	0.0327	0.0506	0.0131	0.0628	0.0974	0.0810	0.0910	0.1584	0.1119	0.1125	0.2479	0.1329	0.1336	0.2609	86.2	86.7	85.9
80	†	0.0096	0.0280	†	0.0228	0.0439	0.0275	0.0431	0.0895	0.0678	0.0631	0.1381	0.1132	0.0926	0.2538	73.1	59.3	83.8
60	0.0041	0.0077	0.0124	0.0127	0.0144	0.0231	0.0223	0.0272	0.0400	0.0451	0.0332	0.0816	0.0838	0.0521	0.1282	53.5	32.3	42.0
40	0.0036	0.0048	0.0089	0.0036	0.0092	0.0109	0.0111	0.0145	0.0239	0.0224	0.0246	0.0314	0.0486	0.0327	0.0334	30.0	19.4	10.4
20	0.0028	0.0032	0.0051	0.0041	0.0039	0.0046	0.0085	0.0076	0.0085	0.0111	0.0101	0.0127	0.0264	0.0164	0.0168	15.2	8.5	4.9
10	0.0036	0.0027	0.0028	0.0028	0.0021	0.0023	0.0042	0.0042	0.0052	0.0065	0.0062	0.0059	0.0093	0.0064	0.0067	3.8	1.9	1.5
Coarser than 10	†	0.0017	0.0026	0.0028	0.0019	0.0019	0.0042	0.0032	0.0048	0.0050	0.0060	0.0046	0.0058	0.0059	0.0068	1.5	1.5	1.5
Refined flour	†	0.0375	0.0763	0.0094	0.0690	0.1083	0.0660	0.0931	0.1447	0.0996	0.1006	0.1955	0.1150	0.1220	0.2215	74.3	78.9	73.1
Sand sulfur	†	0.0045	0.0081	†	0.0092	0.0117	0.0146	0.0165	0.0203	0.0283	0.0243	0.0276	0.0386	0.0227	0.0265	23.3	12.7	8.1
Check	0.0036	0.0008	0.0021	0.0041	0.0012	0.0010	0.0035	0.0018	0.0028	0.0041	0.0032	0.0026	0.0036	0.0036	0.0022			

* Soil 3 had sulfur at the rate of 2,000 pounds per 2,000,000 pounds of soil instead of 1,000 pounds, which was the rate for soils 1 and 2.

† The blanks represent preliminary work which could not be re-checked.

In this study the soils were incubated in earthenware jars after being treated with the different sulfur separates. On two of the soils, sulfur was applied at the rate of 1,000 pounds per 2,000,000 pounds of soil, and on the other, the rate was doubled. Heavy applications were used in order to obtain differences that could be accurately determined. The moisture was maintained at about optimum, or 20 per cent, and the temperature was that of the laboratory.

The different grades of sulfur used were 100, 80, 60, 40, 20, 10 and coarser than 10 mesh, being compared also with the original sand sulfur or composite, containing all the separates in the following per cents, 10.1, 3.3, 9.5, 13.9, 47.1, 16.0, and 0.1 respectively. These were further compared with refined flour sulfur, all of which passed the 100-mesh sieve.

The test was continued for 5½ months. Samplings were made at intervals of 2, 2, 3, 4, and 8 weeks. The samples were dried and the soluble sulfate was extracted with water, 5 parts of water being used to 1 part of soil. The results represent gravimetric determinations. Table 1 shows the size of sulfur particles, and the amount oxidized to sulfate sulfur at each sampling, and the percentage of sulfur oxidized at the final sampling.

With the exception of a few irregularities, there is a consistent increase in the amount of sulfur oxidized with each successive sampling and a consistent decrease in the amount oxidized with increasing coarseness of grinding. The refined flour sulfur, all of which passed the 100-mesh sieve in every case, failed to oxidize as rapidly as the 100-mesh crude sulfur, and in two cases was not oxidized more rapidly than the 80-mesh crude. There is no apparent reason for more rapid oxidation of the crude sulfur.

Material coarser than 40 mesh oxidized very slowly, whereas material finer than 40 mesh was rather rapidly oxidized. The crude sand sulfur as a composite sample was rather slowly oxidized, no doubt because of the high percentage of the coarser material—nearly two-thirds of the composite is coarser than 40 mesh, and only about one-fourth is finer; the 20-mesh size represents almost half the composite.

In what way sulfur application to the soil in the sections of limited rainfall stimulates the growth of legumes is not definitely known. It has been postulated that the sulfuric acid produced brings plant nutrients, and especially calcium, into solution and is for that reason stimulating. It is also believed that the sulfur in some cases at least may stimulate the legume organism and thus indirectly benefit the legume. The slight neutralizing effect of the oxidized sulfur has also been suggested as a cause for stimulation. This suggestion is given more credence since it has been found that many plants, and even the legumes, make better growth in a slightly acid culture solution. Whether the same condition is true in the field, especially for alfalfa, may be open to question.

But whatever may be the reason for the beneficial effect of the sulfur, only a reasonably rapid oxidation under field conditions is necessary or desirable. Even where sulfur may be needed to supply sulfate as plant-food, a sufficiently

rapid oxidation would occur with 40-mesh and the finer materials. Where leaching may occur very rapid oxidation may result in unnecessary loss of sulfate and perhaps other nutrients. A conservative recommendation is to use sulfur all of which passes a 40-mesh sieve. With the finer separates that would naturally be present, oxidation should occur sufficiently rapidly for soil use.

The system of farming, however, may have some bearing upon the degree of fineness advisable. Where very light applications are made annually, fine material should prove preferable. Where a heavier application is applied once in three or four years, coarser material would be preferable. Under such conditions, sulfur ground to pass a 10-mesh sieve would probably give satisfactory results. Only the crude sulfur would seem to be necessary in any case. Aside from the fact that the cost of crude sand sulfur is only about two-thirds that of the fine sulfur, the slow oxidation of the coarser particles should render it more effective through a period of three or four years. For immediate results, however, the finer the material the more effective it should prove.

TABLE 2

Acidity produced from sulfur treatments

	SULFUR MESH									
	100	80	60	40	20	10	Coarser than 10	Refined flour	Sand sulfur	Check
Lime requirement*..........	2,754	2,430	1,072	648	10	0	0	2,754	486	0
pH........................	5.5	5.5	6.1	6.4	6.6	6.9	7.0	5.9	6.6	7.0

* Pounds $CaCO_3$ per 2,000,000 pounds of soil.

ACIDITY PRODUCED

Since sulfur treatment produces acidity, soil 1 was studied to determine the change in active acidity and in the lime requirement. Table 2 shows that the lime requirement (1.2) was increased somewhat in proportion to the sulfur oxidized. The original soil was neutral. The other soils were similar in nature and practically neutral in reaction, and the effect of the sulfur on the reaction should be very similar to the results reported above. Sandy soils which are ordinarily low in both clay and organic matter exhibit very little buffer action, and have small capacity to neutralize acid unless carbonates or alkalinity is present. Consequently, a relatively small amount of oxidized sulfur, may change both the lime requirement and the hydrogen-ion concentration. Such a change would occur very soon after the application of fine sulfur, because of its very rapid oxidation. A continued extensive use of sulfur might produce an appreciable increase in both the lime requirement and the active acidity, and it is conceivable that on soils already slightly acid, the increased acidity might be harmful rather than beneficial. But as the

tendency of arid and semi-arid soils is toward alkalinity, the result would most probably be beneficial.

Since sulfuric is a strong and highly active acid, results common to acid soils, whether desirable or otherwise, will be very marked with a relatively small total sulfuric acidity. The acidity of inactive acid silicates and of easily oxidized and weaker organic acids is much less violent in its effect.

WATER-SOLUBLE CALCIUM

The amount of water-soluble calcium in previous work, some of which has not been published, has proved a rather sensitive indication of the amount of sulfur oxidized. The sulfuric acid produced brings calcium into solution very profusely. The results are shown in table 3 for soil 1 at the end of the experiment.

The large amount of water-soluble calcium might be one reason for the stimulation caused by sulfur on lime-loving plants. It is common knowledge that an application of limestone benefits legumes on sour soils, which are likely to be deficient in available calcium. Though the correction of the

TABLE 3

Water-soluble calcium in air-dry soil

	SULFUR MESH									
	100	80	60	40	20	10	Coarser than 10	Refined flour	Crude sand	Check
Soluble calcium, *p.p.m.*	167	133	125	105	91	87	56	160	100	48

acidity to favor legume bacteria is usually suggested as the major reason for the response of legumes to lime, the supplying of available calcium doubtless is at times an important factor.

Since there is a marked increase in soluble calcium due to sulfur oxidation and subsequent solution, the application of sulfur temporarily functions indirectly to increase the supply of available calcium. This result will doubtless prove beneficial until a dangerously high degree of acidity results, as would seldom occur on soils responding to sulfur, or until the soil supply of calcium is detrimentally reduced by leaching. Where sulfur is used, therefore, it becomes important from the standpoint of calcium conservation, to adopt methods which will prevent unnecessary leaching.

CONCLUSIONS

1. The more finely sulfur is ground, the more rapidly it is oxidized. Sulfur ground to pass a 40-mesh sieve should contain enough fine material to satisfy the most urgent needs for soil use.

2. The oxidation of sulfur increases acidity or neutralizes alkalinity on alkaline soils.

3. The acid produced from the oxidized sulfur brings calcium into solution rather freely.

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